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Deliverable 3.2.

Critical review and synthesis of available methods and metrics for cost-effectiveness assessment

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Abstract

This deliverable (3.2) provides a critical review and synthesis of the available methods and metrics for adaptation cost-effectiveness assessment (CEA).

The review outlines the challenges in applying CEA to adaptation, contrasting this with mitigation. It highlights the risk and sector specific nature of adaptation, the lack of common adaptation metrics across sectors, the greater focus on non-technical options (including building capacity) and the need to consider uncertainty, as key methodological issues, along with baselines, attribution, time-scales, and ancillary effects. Possible ways to address these issues are outlined for the Mediation case studies and the common platform.

The review also outlines some of the more detailed issues with advanced CEA assessments, drawing lessons from the existing mitigation literature on expert versus modelled cost curves, top-down versus bottom-up assessments, adjustments for ancillary effects, discount rates, policy and transaction costs, sensitivity analysis, and learning and innovation.

Finally, the deliverable surveys the literature on applications of adaptation CEA, and summarises possible cost-effectiveness metrics and/or objectives for each sector, providing suggestions for CEA metrics for each of the Mediation case studies.

Summary

This deliverable (3.2) is a critical review and synthesis of available methods and metrics for adaptation cost-effectiveness assessment (CEA). The objectives are to examine the potential use of CEA, the lessons from the existing mitigation domain and to identify potential metrics for adaptation assessment by sector.

Overall, the findings show that the application of CEA to the adaptation domain is possible and could provide a very useful method for decision support. However, it is also likely to require more detailed analysis for mitigation, and unlike the latter, there is no real potential for cross sectoral CEA and cost curve analysis across sectors. The findings are summarised below, along with potential recommendations and initial discussion on use in Mediation case studies.

The Application of Cost-Effectiveness Analysis to Adaptation

Cost-effectiveness analysis is a decision support tool that is used to compare the costs of alternative ways of producing the same or similar outputs. In this respect it is a relative measure, i.e. it provides comparative information between choices. It has been widely used for assessing the least-cost way of reaching given targets, thresholds or pre-defined levels.

The CEA approach has also become the main method of analysis for greenhouse gas mitigation, through the use of marginal abatement cost curves. These curves are constructed by identifying all the expected abatement opportunities, then representing the cumulative abatement potential against a common metric of cost per tonne. Many commentators have assumed that a similar approach can also be used in the adaptation domain. This paper has investigated the application of CEA to adaptation and has identified the following issues.

- Adaptation is generally a response to a local, regional or national level impact, rather than to a global burden as with mitigation. Unlike mitigation, the benefits (and effectiveness) are sector and even risk dependent, as well as being location and often technology specific. This makes the transfer of CEA to adaptation considerably more challenging.
- There are no common metrics (or units) of effectiveness for adaptation across all sectors. This contrasts with mitigation, where a common metric of tonnes of GHG emissions allows all options for all sectors to be ranked directly in terms of €/tCO_2. The lack of a common metric (other than €) makes it is impossible to compare adaptation across sectors using economy wide MAC curves. Further, in many cases, adaptation benefits (effectiveness) also vary within a sector, as adaptation is a response to individual risks, making even sectoral comparison difficult.
- Adaptation requires consideration of a very wide range of options. In mitigation, most studies focus on technical measures (although non-technical and behavioural measures are relevant). For adaptation, soft non-technical options are much more important, and there are additional options of building adaptive capacity. These soft options are much more challenging to cost, and even harder to assess in terms of effectiveness (benefits).
- For adaptation, it is far more challenging to derive a baseline, because the effectiveness of adaptation measures will vary with the ability to adapt (adaptive capacity), and also because of the challenge in projecting future (baseline) socio-economic development and autonomous adaptation.
- The consideration of uncertainty is central to good adaptation, but is very challenging to include in CEA. Unlike mitigation, there is no single central projection to undertake a cost-

effectiveness analysis against – or expressed another way, the use of single central CEA assessments for adaptation will not capture uncertainty and should be avoided. Alternative future projections, e.g. from different socio-economic scenarios and different climate models, will change the absolute level of effectiveness of options, the exact shape of the cost curve, and sometimes the relative ranking of options. Incorporating decision making under uncertainty into CEA requires a more complex approach and considerable resources.

- There are complex issues in the attribution of adaptation options, and there is a potential need to differentiate the benefits that arise from future climate change compared to the benefits in addressing the current climate (and any adaptation deficit, noting this overlaps with baseline issues above). Similarly there are attribution issues in responses to future socio-economic versus future climate change.
- There are multiple attributes (and in some cases, several objectives) that are important when adapting to any individual risk, e.g. the protection of people and also ecosystems for coastal flood risks. In many cases there will also be cross-sectoral effects, e.g. multiple sectors might use a single water supply. Finally, adaptation options often have wider ancillary effects which can be positive or negative, including synergies or conflicts with mitigation. Failure to take these wider effects into account is unlikely to lead to the most appropriate (holistic) adaptation options. However, the presence of numerous attributes complicates CEA, because of the need to consider more than one attribute at the same time in the least cost optimisation. This is in contrast to mitigation, which optimises on one attribute alone (GHG emission reductions). It is possible to address multiple criteria or objectives through simultaneous optimisation, which makes the assessment of adaptation options more complex, or by choosing a single headline indicator. There are also a number of other aspects that are important in ranking options, including distributional effects, the acceptability of options, public perception and political legitimacy.
- The time-scale of analysis is very important, because cost-effectiveness analysis is time dependent, requiring the specification of a base year and a future analysis year. Good adaptation needs to respond to changing risks over time, but this is difficult to include in a cost-effectiveness analysis, other than with multiple assessments in multiple time periods.
- The literature on adaptation also emphasises the need for robustness and flexibility, picking options that are reversible, keeping future options open, and avoiding lock-in. These issues can be advanced through an adaptive management framework, which allows learning, and can consider linkages and inter-dependences, as well as encouraging flexibility through the packages or portfolios of measures. In contrast, CEA tends to pick discrete options and implements these in a strict order.

While this does raise issues, there is still potential for the use of CEA for adaptation, at least at the individual sector level. Considering the issues above, the following ways forward are suggested for Mediation.

- The application of cost-effectiveness to adaptation will need to be context and location specific (noting that this could still be at relatively aggregated scales). This fits with the Mediation approach, and it will be possible to capture these issues with the case studies. However, the analysis will vary with the aggregation level and objectives, and this does raise some issues on how to capture the range of possible uses for the common platform.
- The cost-effectiveness analysis will need to capture sector or even risk specific metrics. Therefore, each case study will need to select specific metrics or thresholds. Again, this raises issues for the common platform, though a list of possible metrics by sector might be a useful addition to address this.

- The application of CEA to adaptation will require consideration of technical and non-technical options. The case studies should seek to ensure that soft options and building capacity are included in the list of potential options. This should also feed through to the common platform, ensuring these options are listed, with some examples or case studies on how to assess costs and effectiveness these types of measures.
- Cost-effectiveness analysis requires baselines, which will vary case by case, according to starting conditions and existing and planned policy. The case studies will need to capture these background issues. This is strongly linked to the choice of socio-economic scenarios, but also extends to the consideration of existing and emerging policy. This makes the analysis more resource intensive but has the advantage of grounding the analysis and making it policy relevant. A further issue is how to include autonomous adaptation and it is suggested the case studies consider such responses, either in the baseline or separately. Finally, it will be useful to explore how adaptive capacity might affect the CEA analysis. All of these various baseline issues are relevant for the guidance on the common platform.
- Adaptation CEA will have to deal with the problem of uncertainty in a much more robust way than has been undertaken for mitigation. The case studies are planning to sample the uncertainty across socio-economic scenarios and climate projections, and this needs to feed through to the cost-effectiveness analysis. The case studies could provide a useful test of different approaches for capturing uncertainty, and avoiding the use of single central projections. A way forward would be to undertake several assessments, e.g. applying the analysis to low, central and high ends of the range of possible climate outcomes, to see how cost-effectiveness varies. These issues also need to be captured in the common platform, and the case studies could provide useful examples to demonstrate this.
- There is an issue of which time periods to consider, given CEA is time dependent. The case studies could consider the cost-effectiveness of current measures for current climate variability / vulnerability, and then look to assess cost-effectiveness in a number of defined future periods. To capture the issues of timing and adaptive management, a minimum of two future time periods are probably needed, e.g. the 2020s and the 2050s. This would provide extremely useful case study examples for the common platform.
- There is a need to capture multiple attributes and cross-sectoral effects. For the case studies, a single headline indicator (a single metric) could be used, but it will be essential to consider other potential costs and benefits in the overall ranking exercise, perhaps through some adjustments to take account of ancillary costs and benefits as well as cross-sectoral issues (including positive or negative effects on GHG emissions). These examples could then also be reported on the common platform.
- The use of decision making under uncertainty is needed for adaptation, but challenging for CEA. The case studies could explore this, e.g. with current and several future time periods, multiple scenarios, etc. and this would provide useful examples for the common platform. However, not all aspects of adaptive management can be adequately captured by CEA, and this should be stressed in the case studies and in the platform.

Lessons from Mitigation CEA

The paper has also reviewed the literature on mitigation cost-effectiveness, to learn from the on-going debate in this area. This has highlighted a number of additional issues that could be relevant for the application of CEA to adaptation. While many of these are complex, and are being addressed in the second generation of mitigation CEA, they do raise useful points:

- MAC curves can be divided into expert-based and model-derived curves. Expert-based MAC curves assess the cost and reduction potential of each single abatement measure, while model-derived curves are based on a range of partial- or general-equilibrium models. For adaptation, most initial assessments (including in Mediation) are likely to be expert based, though there may be potential for model based analysis in some sectors.
- Top-down versus bottom-up. There are differences in the results of mitigation CEA depending on whether studies use a sector, technology rich bottom-up approach, or a top-down, economy wide analysis. Within the early application of CEA to adaptation, the former is likely to dominate (and will be the approach used in Mediation), but for some major areas, consideration of the wider top down effects would be useful in the future.
- Consideration of ancillary effects and external costs and benefits. There have been some applications of CEA which seek to build in ancillary effects, either through the use of cost-effectiveness adjustments or through multi-optimisation analysis. These effects involve a step change in complexity and resources, but do provide potential lessons for the future.
- A key area of discussion has centred on discount rates, and whether to use a social or a private sector discount rate. Recent examples in mitigation CEAs have undertaken sensitivity analysis with both, to examine whether this alters the ranking and overall costs of compliance. This reflects a possible good practice example for adaptation and for the Mediation project.
- The mitigation CEA literature has identified a difference between technical versus policy costs, the latter including transaction costs. This highlights that use of the technical costs alone under-estimates the costs of options (and thus over-estimates the relative cost-effectiveness). This is relevant for adaptation and some consideration of policy costs would be useful for Mediation.
- The baseline assumptions, including the technology and reference costs (e.g. future energy prices), affect the cost-effectiveness analysis. This is worth considering for adaptation CEA and for sensitivity analysis in Mediation, particularly for some sectors.
- There is an increasing recognition that CEA needs to address uncertainty more robustly, rather than only assessing central projections and presenting single central outputs. This involves testing the effects of uncertainty in cost estimates, but also in baseline projections and assumptions. The use of such sensitivity analysis provides useful lessons for adaptation and for Mediation studies.
- Most MACC assessments have limited feedback between sectors or even time periods. Furthermore, they are defined with respect to a certain year. Addressing these issues is more important for adaptation, to capture the elements of iterative adaptive management and to ensure options are kept open and lock-in is avoided. There has been some progress in considering such issues, which provide useful lessons for adaptation.
- There has also been a debate around learning curves and innovation, which are important in determining the balance of current versus future options. This is something which requires consideration in the adaptation domain, albeit in more complex assessments.

Identification of CEA Metrics for Adaptation by Sector

The report has reviewed the potential metrics of adaptation cost-effectiveness analysis by sector. This includes possible common units, but also possible sectoral objectives. These are summarised by sector in the table below.

Examples of possible metrics / objectives for adaptation cost effectiveness analysis

Sector	Possible Metric	Issues
Health	Cost per DALY, cost per fatality or cost per life year saved (all impact metrics). Some health thresholds exist (maximum occupational temperatures, comfort levels)	Different cost per life year across Europe. Not capture occupational health. Consistency issues with other sectors where health a part of wider risks (e.g. floods, transport)
Sea level rise and other flood risks	Cost per reduction in land area at risk or number of people at risk (exposure metric) or expected annual damages (economic metric) Cost per ha. For the measure relative to value of land protected per ha (impact metric). Pre-defined acceptable risks of flooding as objective / threshold level for adaptation	Land area and ha only covers small sub-set of SLR impacts. Issue of non-market values, loss of biodiversity and ecosystem services. Very different levels of acceptable risk and protection across Member States
Agriculture	Impact based metrics include cost per unit of crop yield, reduction in water stress, production or land value. Possible headline indicator is cost per change in value added as a result of adaptation measures.	Issue of capturing wider environmental and multi-functionality of agriculture Highly aggregated and only one element of potential impacts.
Water resources	Impact metrics for water availability (household) and cost per M^3 of water provided. Possible thresholds in terms of environmental quality (Directives) or acceptable flows. Possible thresholds for risk of supply disruption.	Issues with wider attributes of water including quality (environmental). Issue were multi-functionality and multiple users and sectors (agriculture, industry, etc.)
Ecosystems and Biodiversity	Critical targets (sustainable levels) and standards (overall objective). Possible cost per unit of ecosystem services.	Issue if standards are available (and complex and contentious to set).
Business & industry	Possible headline indicator is cost per change in value added as a result of adaptation measures. Could also include acceptable risk levels for infrastructure or service supply.	Broad nature of sector and potential risk.
Cross-cutting theme		
Extreme Events (including infra-structure)	Possible metric in terms of cost per level of risk reduction, or pre-defined acceptable levels of risks as objective	Very different levels of acceptable risk and protection across Member States Variability in risk acceptability across different extremes, and for different infrastructure.

It is highlighted that in many cases, the relevant metric will change with the study objectives, the aggregation level (national vs. local) or the time-scale (short-term versus long-term). The analysis demonstrates that the application of CEA will be easier for some sectors than others. It is also reveals that in terms of sector objectives, there are differences between Member State (e.g. in relation to existing objectives, such as acceptable levels of flood risks).

The review has found and reported on CEA examples in the floods, water and health sectors. While these provide useful examples of the application of CEA in the adaptation domain, these studies ignore nearly all the methodological challenges highlighted earlier, i.e. most studies optimise on individual given climate scenarios, they focus on headline indicators and generally ignore other criteria (including wider costs and benefits), etc.

Discussion of Cost-Effectiveness Analysis in the Mediation Case Studies

The final part of the review has been to consider the potential for cost-effectiveness analysis in the Mediation case studies. The results are summarised below, and show that for most case studies, some initial form of CEA should be possible, at least for some deterministic analysis in the short-medium term.

Potential for Cost-Effectiveness in the Mediation Case Studies

Location	**Main theme**	**Cost-effectiveness potential**
Nordic countries	Health/elderly - Vulnerability mapping	Use of CEA based on cost per death or illness (or DALY) avoided.
Finland	Land-use/biodiversity	Potential use of CEA for biodiversity protection, if ecosystem sustainability limits available, though analysis of effectiveness may be challenging.
Rhine basin	River discharge	Possible use of CEA in terms of acceptable (tolerable) levels of flood risk, but possible issues with cross-sectoral issues
Netherlands	Salt water intrusion	Possible use of CEA for protection or acceptable level of risk of intrusion.
Rhine Germany	Forest in flood plains	Possible use of CEA in terms of acceptable (tolerable) levels of flood risk, or consideration of cost per unit of improved forest production. Issue of wider forest services could be captured by ecosystem thresholds.
Albania	Water scarcity/ agriculture/hydropower	For water scarcity possible use of CEA on acceptable risk levels of drought or costs of supply (M^3 delivered). Alternative would be to consider agriculture in terms of yield improvement or value added. For hydropower could be based on levels of supply disruption or minimum annual generation.
Serbia	Water scarcity and quality/agriculture	For water scarcity CEA possible for acceptable risk levels of drought or costs of supply (M^3 delivered), or agriculture in terms of yield improvement or value added.
Poland/ Wroclaw	*Urban problems*	More information needed.
Poland	*Flood safety*	Use of CEA in terms of acceptable (tolerable) levels of risk
Tuscany	Agriculture and landscape	Possible use of CEA in terms of yield improvement or value added. Landscape more challenging to consider.
Tuscany	Heat and tourism	For health, use of CEA based on cost per death or illness (or DALY) avoided. Tourism more challenging to consider.
Guadiana	Droughts/agriculture	For water scarcity possible use of CEA for acceptable risk levels of drought or costs of supply (M^3 delivered). Alternative would be to consider agriculture in terms of yield improvement or value added. Issues of capturing multiple sectors and also ecosystem aspects (multiple attributes and sectors)
Guadalqivir	Droughts/agriculture	
EU-wide	Agricultural yields	Possible use of CEA for yield improvement or value added
EU-wide	*Floods*	Use of CEA in terms of acceptable (tolerable) levels flood risk
EU-wide	*Forest fires*	Possible use of CEA in terms of levels of acceptable fire risk.

Contents

1. Introduction

1.1 Objectives

The Mediation study (Methodology for Effective Decision-making on Impacts and AdaptaTION) is assessing climate change impacts, vulnerability and adaptation through a generic and context-specific knowledge, and aims to develop an overarching integrated methodology and a flexible, interactive common platform for knowledge sharing.

One important part of this is the need to consider the costing of impacts and adaptation options, and this is being tackled in work package 3 of the project: **Methods and metrics for socio-economic evaluation of adaptation strategies including cost-effectiveness.**

Early progress in this work package was focused on a review of available methods, collated in Deliverable 3.1 (Report on review of available methods for cost assessment: Zhu and van Ierland, 2010). This deliverable focuses down on one particular method, cost-effectiveness analysis, and provides a review and inventory of available methods and metrics. The description from the DOW is presented in the box below.

Description of Work

Task 3.2: Inventory of available methods and metrics for cost-effectiveness analysis This task involves an inventory of associated methods and metrics, and criteria for their applicability for the cost-effectiveness of adaptation options and measures. It will include assessment of costing methods for sectors that are currently sensitive to climate (climate variability) as well as looking at methods for future climate change. It will have a strong focus on the issues with non-technical as well as technical measures.

D.3.2. Critical review and synthesis of available methods and metrics for cost-effectiveness assessment.

1.2 Introduction to Cost-Effectiveness

Cost-effectiveness analysis (CEA) is a decision support tool. It allows a comparison of the costs of different options for achieving the same or similar outcomes, either in relation to individual options (e.g. at the project level), or through the combination of many options in relation to programme or policy objectives. In this respect it is a relative measure, i.e. it only provides comparative information between choices – it does not provide absolute information that provides a justification for the policy itself, as with cost-benefit analysis (CBA).

In the European environmental context, the approach was widely used in the early analysis of air quality policy, looking at the costs of emission reductions towards achieving critical load thresholds (e.g. see Watkiss et al, 2007). This provides a classical use of the approach, where a policy target was set on a scientific basis, and then the costs of alternative ways of achieving this target (or progressing towards it) were assessed. More recently, it has become the default approach for the analysis of the costs of mitigation policy.

The approach can be used in a number of alternative ways.

- It can be used to at the costs of achieving pre-defined policy targets or objectives, whether these are defined for protection (e.g. ecosystem sustainability) or acceptable levels of risks. This can also include the consideration of major thresholds or tipping points.

- It can be used to examine the rising costs of progressively higher environmental improvements. In this way, it can actually be used to set a target or goal, i.e. the point at which costs become disproportionately high.
- It can be used to consider the level of improvement with a pre-defined budget.
- It can be used as a threshold or benchmarking tool, for example, where a cost-effectiveness value is set, and subsequent measures are compared against this. A good example of is with the costs of new health care treatments. In the UK, the National Institute for Public Health and Clinical Excellence (NICE) uses a cost-effectiveness metric to compare new drugs and measure their clinical effectiveness in terms of value for money. It uses a cost per Quality Adjusted Life Year (QALY) to compare how much life can be extended and improved, and compares this to the costs of the drug or treatment, expressing as a cost per QALY. This is then compared against a cost-effectiveness threshold or benchmark: if a treatment costs less than £20,000-30,000 per QALY (midpoint £25,000), then it is considered cost effective (NICE, 2010).

Some examples of reported definitions are presented in the box below. It is stressed that a number of these are somewhat misleading, for example, the IPCC AR4 WGIII definition, in describing CEA as 'a special case of CBA', completely misses the underlying framework, structure and thinking behind the approach.

Definitions

Cost-effectiveness analysis (CEA) - A decision-making tool that compares the cost of different options for achieving the same or similar outcomes.

Source UK Department for Environment, Food and Rural Affairs
http://www.defra.gov.uk/environment/policy/natural-environ/using/valuation/glossary.htm

Cost-effectiveness analysis takes a predetermined objective (often an outcome negotiated by key stakeholder groups in a society) and seeks ways to accomplish it as inexpensively as possible

Source: IPCC (2001). Glossary, Third Assessment Report. Ahmad et al. 2001.

Cost-effectiveness analysis. A special case of cost-benefit analysis in which all the costs of a portfolio of projects are assessed in relation to a fixed policy goal. The policy goal in this case represents the benefits of the projects and all the other impacts are measured as costs or as negative costs (co-benefits). The policy goal can be, for example, a specified goal of emissions reductions of greenhouse gases.

Source: IPCC (2007). Glossary. Working Group 3 (Verbruggen), 4th Assessment Report.

Cost-effectiveness analysis (CEA) is also used to evaluate trade-offs between benefits and resource costs. However, in contrast to CBA, the benefits are measured in units other than money. Moreover, the output (or benefit) of the policy/programme/project is the same or similar for all options considered. It can be used to identify the highest level of a physical benefit given available resources (e.g. delivering the maximum reduction in risk exposure subject to a budget constraint), as well as the least-cost method of reaching a prescribed target (e.g. the supply of a given quantity of potable water).

Source: UKCIP (Metroeconomica, 2004), Costing the impacts of climate change in the UK.

1.3 Simple Example of a Cost-Effectiveness Analysis

There are several guidance documents on the application of cost-effectiveness analysis (EA, 2000, Defra, 2008 and many more). This section provides a very simple example as an illustration. Note that the exact approach will vary significantly with the policy context and question. In very broad terms, cost-effectiveness assessment involves two broad steps.

1. To assess and rank the cost-effectiveness of individual options.
2. To build these ranked options into a cost curve.

Note that some studies only undertake the first of these steps, i.e. for simple project examples, there is often no need to produce a cost curve (the ranking provides a way of choosing between options). Similarly, in some cases, the compilation of cost curves will be too complex or beyond the resources of a study. For these reasons, these two steps are considered separately.

Assessing and ranking the cost-effectiveness of individual options

There are a number of common steps in undertaking a cost-effectiveness assessment. These are (in very general terms);

- To collate a full list of options (technical and non-technical), preferably as wide as possible;
- To evaluate the potential benefit of each option, i.e. the benefit over the lifetime. In many but not all cases, these are then normalised as an annual benefits. Note that the benefits are often assessed against a baseline or reference case.
- To collect cost data for each option - noting this involves the full economic costs over the lifetime of the project, including capital and operating costs - and to adjust these costs to present data in terms of a common base year. Note also that in the planned adaptation context, this cost assessment should be consistent with the relevant assessment framework and accounting of different cost element (e.g. with Government appraisal guidance). Note in cases this may also be compared against a baseline of reference case;
- To determine the present value of each measure's cost stream. Note in many but not all cases, these are then expressed as equivalent annual cost over the life of the option;
- To estimate the cost-effectiveness by combining the outputs above, by dividing the lifetime cost by the lifetime benefit (or annualised costs by annualised benefit) to derive the cost-effectiveness of the measures (e.g. cost per tonne);
- To rank or prioritise measures in order of cost-effectiveness.

In very simple terms, cost-effectiveness involves the combination of the effectiveness (the likely reductions in the risk or environmental problem such as the reduction in GHG or air pollution) with the economic costs of implementing the measure, expressing cost-effectiveness as cost (£) to reduce one tonne of GHG emissions, or cost (£) to improve air quality by 1 $\mu g/m^3$. Options are ranked initially order of their cost-effectiveness.

In many cases, e.g. greenhouse gas emissions and air pollution, both costs and benefits are expressed as annual terms. However, in other cases, the CEA may use lifetime values (lifetime benefits and present values). Note that in practice, the choice between a PV or equivalent annual cost does lead to subtle differences in the ranking of measures on the cost side (even when annual benefits of a measure are consistent over time). On the benefit side, the difference is important between life-time versus annual benefits for measures which have a declining benefit against the baseline over time.

Calculating Effectiveness (Benefits)

The first step is to estimate the potential benefits of the options or measures. This is often (but not always) expressed in annual terms. As an example, this can be derived as following

$$QA^k = E_s^k \sum_{s=1}^{S} A_s$$

where

QA^k = the annual quantity of pollutant abated by measure *k*,

E_s^k = the effectiveness of measure *k* in reducing emissions from source *s*,

A_s = the annual emissions of pollutant per unit (e.g. per vehicle) from source *s*,

Note that when subsequently building up the cost curve, the additional term is needed.

S = the total number of sources for which measure *k* is applicable.

Calculating Costs and Equivalent costs.

The costs of adaptation need to be presented such that various measures with different economic lives can be compared. This is a fairly standard estimation in cost-benefit analysis, with present value of a measure's cost stream (over the life of the measure) is calculated, noting this relates to the real economic costs rather than the financial costs. For example, (EEA, 2000) for a base year (denoted as *t* = 0), the present value of each measure's total cost stream is calculated using:

$$PVC_0^k = \sum_{t=0}^{T^k} \left[NRC_t^k + RC_t^k - SRC_t^k\right] \circ \left[1 + r\right]^{-t}$$

where

PVC_0^k = the present value of the total cost stream for mitigation measure *k* in year zero,

NRC_t^k = the non-recurring cost of mitigation measure *k* in period *t*,. i.e. the one-off costs incurred to install/implement the measure *k* in period *t*, and the time required to install/implement.

RC_t^k = the energy and non-energy recurring costs to operate mitigation measure *k* in period *t*,

SRC_t^k = the savings in recurring costs resulting from operating mitigation measure *k* in period *t*,

T^k = the operating life of mitigation measure *k*, and

r = the appropriate real discount rate (as a fraction).

To match this to the usual annual metric for benefits, costs are expressed in an annual term, i.e. an *equivalent annual cost or annualised/levelised cost*. For example, using following formula.

$$EAC = PVC\left[\frac{r(1+r)^T}{(1+r)^T - 1}\right]$$

This can be compared against the annual benefits of the scheme (e.g. reduction in emissions) to provide the cost-effectiveness ranking, e.g. the equivalent annual cost per tonne abated, i.e. = EAC/QA. Note that the choice of annual versus lifetime estimates in CEA can influence the relative choice of measures (i.e. the relative cost-effectiveness).

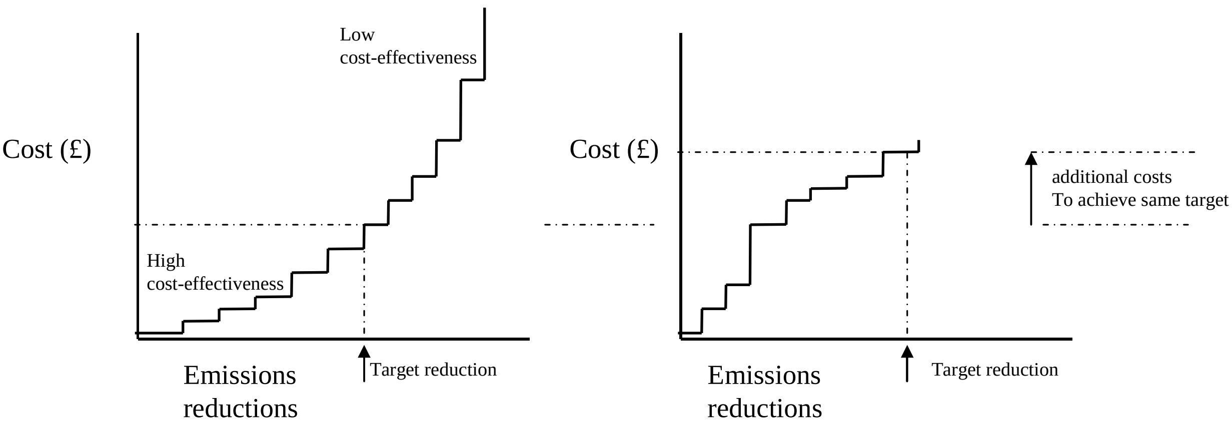
Note that the approach used to the analysis, i.e. the discount rate used, whether real or nominal rates are used, constant or current prices, etc. will depend on who is doing the analysis, e.g. whether as part of standard government economic appraisal, private sector investment analysis, etc.

For Mediation, we generally assume public sector planned adaptation analysis, thus government analysis of options, so the cost analysis would be similar to routine CBA type assessment, e.g. see HMT guidance on economic appraisal, 2007: EC guidance on impact assessment, EC, 2005.

1.4 Cost Curves (and Costs of Compliance)

The information from a cost-effectiveness analysis above can be used to build up a cost curve, which can look at the cumulative potential (in reducing risks) of several options, and can look at estimating the least cost way to achieve predefined targets or objectives. To do this, additional information is needed to estimate the cumulative potential reduction in risks from each option. In the case of GHG emissions (and air quality) this is compiled from emission inventories, themselves a function of the activity data and baseline emission factors. For other areas, this analysis can be more complex.

In very simple terms, the cost curve works by introducing those measures that are most cost-effective first, noting the cumulative reduction in risks (e.g. the cumulative GHG emission reduction) that they achieve, and then progressively introducing less cost-effective options (each with an associated cumulative reduction in risk). Where there are predefined targets or objectives, this process can carry on until the target level is achieved, or until proportional progress towards the target can be demonstrated. The graph below on the right shows what happens if the cost-effectiveness order is changed. By reading off to the cost axis, it can be seen that this significantly increases (moves upwards) the costs of achieving the target.



If introduce in order of cost-effectiveness, i.e. then can estimate how to achieve target most cost-effectively as well

Without cost-effective introduction achieving the same target reduction leads to much higher costs

Cost curves can therefore estimate the least cost (economic efficient) way of achieving objectives, e.g. predefined policies or objectives or thresholds. A key strength is that it does not require information on the economic benefits and valuation, and can assess targets set by scientific information or through societal or ethical choices[2].

The cost curves (for mitigation, specifically marginal abatement cost curves) are a form of least cost optimisation, which can be derived by expert analysis, or from bottom-up or top-down models (or both).

An explanation of the curves – as used in the mitigation domain (marginal abatement cost curve or MACC) – is presented in the box below. In this case, cost curves are constructed by identifying all the expected abatement opportunities for a particular time period in order of

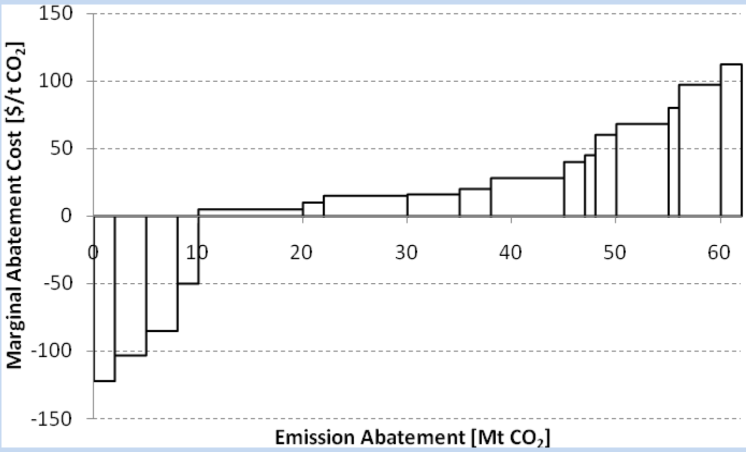
[2] Note CBA and cost-effectiveness are not necessarily exclusive, and there are examples of policy decisions where both approaches are used to complement each other, a good example being the air quality policy analysis undertaken by the European Commission as part of the Clean Air For Europe programme (EC, 2005).

cost-effectiveness (i.e. a ranking of options, e.g. Cost per tonne of CO_2 abated), and representing their cumulative abatement potential along the horizontal axis. The vertical axis then represents the cost of abatement for each of these opportunities. The curve then gives a representation of the total cumulative abatement that would be achieved at a particular cost-effectiveness.

Marginal Abatement Cost Curves

Many of the studies on low carbon analysis use a Marginal Abatement Cost Curve (MACC)-based approach. A MACC is a graph that is used for usefully highlighting the 'best' or most cost-effective options for reducing emissions across the economy, as well as the total emissions achievable for different levels of costs. They present the marginal cost of emission abatement for varying amounts of emission reduction. This is shown in the graph below.

Each bar on the graph represents a specific measure, with the vertical axis indicating the costs that each of these measures can reduce a tonne of CO_2 at (the cost-effectiveness of abatement). Thus the costs of reducing emissions increase from the individual options (the bars) from left to right. The width of each bar on the horizontal axis indicates the total potential reduction associated with each measure (in tonnes of emissions), thus wider bars represent options that can reduce more emissions than narrow bars. The total cost of each measure if fully implemented is therefore the marginal cost (y-axis) multiplied by the abatement potential (x-axis).



The cost curve therefore presents options in terms of their cost-effectiveness. It orders these in terms of attractiveness or cost-effectiveness from left to right, thus the most favourable options are those in the bottom left of the graph, i.e. in this case where they are below the zero lines, they imply that it is possible to reduce carbon emissions at negative cost (no regret options). These are typically observed for efficiency measures that reduce fuel consumption. By reading off the graph, it is possible to see the amount of emissions that can be abated for different cost levels.

MACCs always consider cost-effectiveness in a specific year, and against a baseline in that year. The baseline is critical for informing what the potential abatement is e.g. if there is significant coal generation assumed in the baseline, there will be greater potential than if generation was predominantly gas-based.

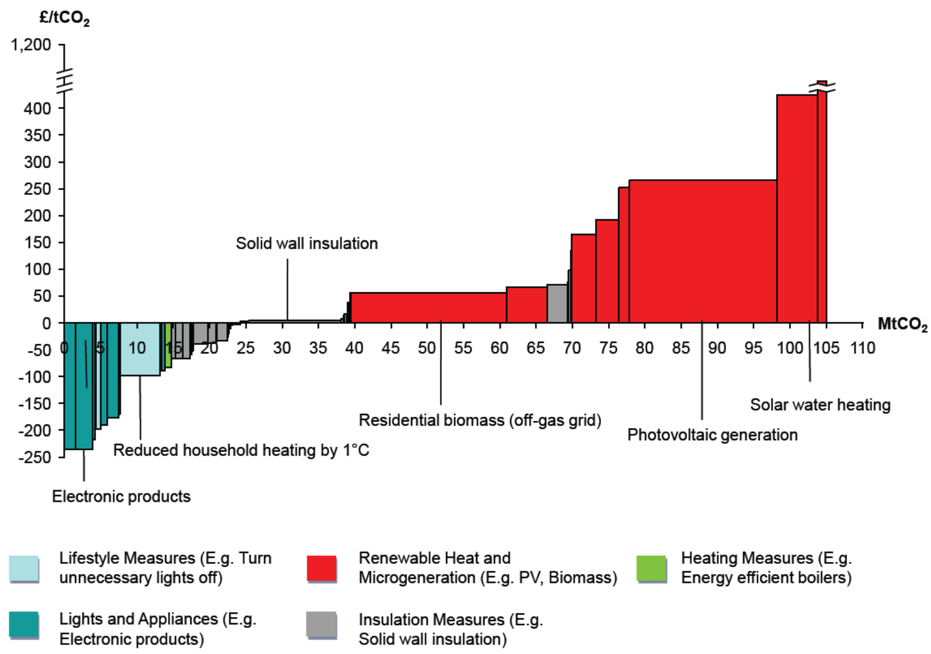
Whilst recognising the importance of this approach, particularly for informing policymakers about abatement potential, there are some inherent weaknesses of this approach.

Source: Updated from SEI (2010)

This type of approach has been used extensively in European and Member State analysis of mitigation costs.

A particularly extensive analysis was undertaken in the UK, by the Committee on Climate Change, in their analysis of potential UK carbon budgets, as part of the UK Climate Change Act (CCC, 2008). They produced marginal abatement cost curves for various sectors, e.g. residential sector (shown below) power generation, transport, agriculture, etc. The cost curves were combined to allow an analysis of the cost-effectiveness to see how to achieve a target level from the range of options across the economy, more specifically in the case of the UK, to look at the costs of emission reductions in the traded and non-traded sectors.

Figure 6.10 Residential sector MACC – technical potential in 2020



Source: CCC

Source: CCC, 2008

A cost-effectiveness analysis allows the estimation of the relative costs of different options up the cost-curve. It can be used to see whether an incremental tightening of targets is associated with rising costs and whether these increases in cost are at some point disproportionate (noting that while this is arbitrary, it is often indicated by a step change or discontinuity in the cost curve). There are policy examples where such analysis has led to a lowering of ambition (e.g. for the Defra, 2006: Climate Change Programme Review[3].

While the application of cost curves seems simple, in practice, it is much more complex. This is discussed in a later chapter, reviewing the issues with the application of cost-effectiveness analysis, drawing on the mitigation lessons.

However, a key issue for Mediation is the application of cost-effectiveness to adaptation. This is discussed in the next chapter.

[3] In this example, the cost-effectiveness analysis found that achieving the original UK domestic goal to achieve a 20% reduction in CO_2 emissions by 2010 would lead to very high marginal costs; on the basis of this, and other considerations, the review instead recommended a set of measures that took the UK ‘close’ to the 2010 goal (a 15 – 18% reduction instead) – see Watkiss et al, 2008)

2. Applying Cost-Effectiveness to Adaptation

The previous chapter provided the background to cost-effectiveness analysis. In the mitigation domain, the use of CEA has become extremely wide-spread, not least because it allows a means to compare mitigation options in common terms, i.e. across different sector.

In theory, a similar exercise could be undertaken for adaptation, using common metrics. However, adaptation differs to mitigation in many respects. This chapter explores these differences.

2.1 Adaptation is Local in Nature

Adaptation is often considered a response to a local impact, rather than to a global burden as with mitigation. In practice, adaptation can be defined at the local, regional, national or even European scale, though the impacts being addressed will be different at each aggregation level.

With mitigation policy, a common MAC unit and cost curve can be derived, because emissions (and emission reductions) have the same effect irrespective of location, i.e. the burden leads to an identical impact.

In contrast, any benefit achieved by adaptation is primarily local/regional, and is determined strongly by local conditions. The level of benefit achieved by adaptation is therefore site specific.

2.2 Benefits (Effectiveness) are Sector and even Risk Specific.

The impacts of climate change - and therefore the measurement of effectiveness (benefits) using cost-effectiveness - are sector specific, involving different types of climate signals and impacts.

Climate Change involves a very large type of potential 'risks', which are very different in nature, e.g.

- The existing vulnerability from current climate variability and extremes (including the current adaptation deficit).
- The potential changes from future slow onset changes (e.g. average temperature change, average precipitation).
- The potential changes in the frequency or severity of extreme events (e.g. the changes in flood return periods, or increases in heavy precipitation event intensity)
- The combined effects of average trends and changing variability acting together,
- Possible major effects, including the exceedence of thresholds (and limits of adaptation).

This impact on a very large number of activities, across many sectors, leads to an extremely large list of potential impacts, along with cross sectoral risks (either where combined effects occur, or where impacts in one sector lead to impacts in another).

As an illustration of the scale of risks involved, recent work in the UK (UK Climate Change Risk Assessment, 2010) has identified over 600 different risks that climate change might have on the UK, of which 140 are considered potentially important.

Furthermore, all of these risks change dynamically over time, i.e. they evolve in nature, meaning that any assessment of the benefits of adaptation using cost-effectiveness has to capture different effectiveness for different time periods (responding to different risks).

There are therefore no common metrics in relation to what a given level of adaptation achieves, in contrast to mitigation where there are common units of reduction across all sectors (tonnes of GHG emissions, which can then be expressed in common units of cost-effectiveness,€/tCO_2).

To illustrate, there is not a common physical metric of benefit between a reduction in risk from coastal flooding vs. a reduction in cooling demand delivered from a passive air cooling system in response to higher summer temperatures. The only common metric is money, though this then largely leads to a cost-benefit framework (discussed in another deliverable).

Adaptation benefits (or effectiveness) also varies within a sector according to whether the option is responding to impacts from average temperature changes or sea-level rise, or the change in probability (or magnitude/frequency) of extreme events such as flooding, etc.

It is therefore impossible to compare cost-effectiveness of adaptation across different sectors using economy wide MAC curves, and it is even difficult to make this comparison even across a sector, because in practice there may be a variety of adaptation response to different sectoral impacts (e.g. coastal flooding vs. coastal erosion from SLR).

As highlighted in the previous chapter, cost-effectiveness is a relative measure. Therefore, for adaptation, it can only provide consistent relative information if there are common end metrics (i.e. targets for optimization are expressed in the same or in assumed equivalent terms), or to put another way, the availability of common metrics between risks or within a sector determines the level of cost-effectiveness possible.

2.3 Adaptation Requires Consideration of a wide Range of Options

MACs are usually applied for technical options, because these are easier to cost in terms of their costs, as they have defined investment and operational/maintenance costs, but also easier to assess in terms of the physical improvements and effectiveness they achieve.

Few analyses consider measures associated with structural changes (e.g. spatial planning, urban transport systems, economic restructuring), non-structural measures (e.g. annual sand supplementation along costs), and non-technical options including behavioural change (demand-side focus, awareness raising, etc.). The reason is that such measures are not easily included. For non-structural options, the focus is often on the relatively high operational and maintenance costs (rather than upfront investment). For behavioural change, it is the difficulty in estimating costs at all (noting these have to include resource costs).

The lack of consideration of non-technical, non-structural options, and especially the omission of capacity behavioural change, is an important gap in most CEA approach.

For adaptation, these soft, non-technical options are likely to be particularly relevant, including the need for institutional options and capacity building, recognising the recent adaptation literature.

Unfortunately, there is less information on these soft measures, and it can be extremely difficult to estimate the costs of building adaptive capacity or even the costs of soft options.

A further issue is that there may be differences in the adaptation response achieved (in magnitude) according to whether implementation is proactive or reactive.

Omission of these ‘soft’ options would fail to capture many of the most promising options. A greater focus is therefore needed on them in analysis.

2.4 Defining Future Baselines

In order to undertake a cost-effectiveness analysis, a baseline is needed, to compare the effectiveness of options against. In the mitigation domain, a technical baseline is relatively easy to compile, as it is based on measured or projected quantitative assessments. For adaptation, it is far more challenging to derive a baseline for a number of reasons.

A number of key points are highlighted.

The future effectiveness of adaptation options will depend on exposure to current and future risks, which has a much more local nature than say GHG reductions. The consideration of current risks also leads to the concept of the adaptation deficit, defined as a failure to be adapted adequately to existing climate risks.

The future effectiveness of adaptation measures will vary across actors depending on their ability to adapt (adaptive capacity).

The future effectiveness of adaptation measures will be determined by the baseline socio-economic development, whether this is population growth, income levels, or more general levels of development (e.g. sustainable worlds, land-use policy, etc.).

The future effectiveness of adaptation measures that are planned by Government will be affected by the autonomous adaptation that occurs, whether this is due to physiological acclimatisation (e.g. physiological acclimatisation to heat), automatic (increases in cooling demand from thermostats), behavioural autonomous adaptation (changes to behaviour that reduce risks), technical private (individual) actions, etc.

2.5 Multiple Scenarios and Uncertainty

Baseline impacts of climate change, and therefore the benefits (and effectiveness) of adaptation options, are determined by the socio-economic scenario, the climate model used, and the analysis of impacts (impact assessment).

In most mitigation cost-effectiveness, a single central future projection is taken, to undertake the cost-effectiveness analysis against. While there are future uncertainties, e.g. in terms of baseline GDP, energy prices, energy use, emissions, etc. these are generally excluded, though some better studies do undertaken sensitivity analysis. For adaptation, however, these complexities are much more pronounced, and are especially important in the context of the future climate model projections, i.e. there is not one single central projection to undertake cost-effectiveness analysis against.

As an example, the suite of future SRES scenarios would give six alternative futures. Further a suite of different climate models, run for each of these scenarios, would produce very different outputs on the level of climate change, and thus the level of potential impacts under the baseline scenario. Finally, depending on the impact models and approach used, these would translate into a very wide potential range of future baseline impacts.

It is against this landscape of uncertainty that a cost-effectiveness analysis would have to optimise. Clearly, the baseline will be different for each combination of SRES scenario, climate model and impact model. Therefore, the cost-effectiveness of options would differ between each combination of these parameters, either in terms of the unit effectiveness (the level of benefit possible), the cumulative potential that the option could achieve (i.e. the width of the bars in the cost curve).

It is highlighted that alternative baselines (uncertainty) will change the level of effectiveness and the overall shape of the cost curve, but it will also potential change the order of the options. This is also true for mitigation, but for adaptation it is a particular issue in cases where the climate models show wide ranges (e.g. for precipitation, where the bounded ranges from the climate models often show contradictory results, with rainfall projected to increase in some regions with some models, but reduce in the same regions with alternative models).

Taking this to the logical conclusion, an analyst would have to produce a cost-effectiveness analysis and a cost curve for each scenario, or at least sample across the range of uncertainty. This has significant resource implications, as well as increasing the analytical difficulty and the presentation of results.

2.6 The Question of Timing

Cost-effectiveness analysis is a time defined analysis, i.e. it requires the specification of a base year and an analysis year. In mitigation, this is commonly 2020 or 2030, though some assessments have also looked at the inter-dependencies with multiple years (see next chapter).

For adaptation, the timing issue is key because adaptation cannot be viewed as a simple set of options, implemented in specific year – instead it involves a complex and evolving suite of options that may vary over time, and require learning and iteration. These timing effects are extremely difficult to include in a cost-effectiveness analysis, without multiple assessments in different time periods. Thus, they effectively go beyond CEA.

In practice, it will be possible to apply CEA to adaptation for the short-medium term, i.e. out to 2030 as applied in mitigation. For longer time-scale it will be more challenging, but a 2050 analysis is possible also. Analysis beyond this time-scale is really beyond the limits of the approach, not least due to the issues of uncertainty, though there might be some potential in a longer-term risk context.

There are further issues with the timing of adaptation, because benefits will be determined by the potential impacts or change in risk in any future period, or in cases, where adaptation potential of certain measures is exceeded. Thus analysis in 2050 will generate better cost-effectiveness for options, because underlying risks are greater (though note that costs will change over time, and in spatial planning, costs may increase if no spatial reservations have been made).

The main finding is that for adaptation, cost-effectiveness is very dynamic, i.e. it will vary according to the time period, and options and measures are likely to alter in their relative cost-effectiveness over time.

There is also the question of the appropriate discount rate. The cost-effectiveness of options may vary according to the discount rate used, and this may be important particularly for longer-term options. This is discussed in the next chapter.

2.7 Multiple Attributes Including Ancillary and Cross-Sectoral Effects

Cost-effectiveness usually focuses on one attribute or objective at a time[4]. In the case of mitigation this is GHG emission reductions, i.e. the cost curves function on the single attribute of GHG emission reduction.

As the above discussion highlights, adaptation involves multiple metrics, even within a sector, requiring multiple optimisation (unless a headline indicator is chosen).

Therefore, even when considering the impacts of one risk, say sea level rise, there is an issue of capturing the full risk of impacts that occur, and that options can be measured against. For example, for SLR, is loss of land, property damage, coastal erosion or salt water intrusion the metric that should be used in the cost-effectiveness analysis – or can some complex multiple optimisation pick out the option that performs best against all of these criteria?

In many cases, CEA will require the choice of a single optimisation parameter, i.e. a single headline indicator metric, which may lead to conflicts when these lead to options that do not improve (or even increase) other impacts.

Further to this, adaptation options often have wider ancillary effects of adaptation, either positive or negative, which might affect the relative ranking of adaptation measures.

They also frequently involve multiple sectors, or multiple risks (see discussion above), often cross-sectoral in nature.

Finally, in line with appraisal, there are a range of other aspects that are important. These include the distributional effects – in relation to the underlying impacts – but also the potential adaptation options (i.e. whether they have distributional benefits, e.g. where costs or benefits accrue to different groups, e.g. for example when costs accrue to socially deprived groups, etc.). It also includes the acceptability of options, including public perception, but also political legitimacy

2.8 Decision Making Uncertainty (Robustness, Flexibility, Reversibility)

The literature on adaptation emphasises the need for robustness and flexibility, picking options that are reversible, keep future options open, and avoiding lock-in, i.e. working within an iterative adaptive management framework (e.g. Lempert et al, 2007). It is difficult within the narrow framework of cost-effectiveness to capture these attributes, not least because CEA tends to work with defined baselines and time periods.

Furthermore, one of the elements of decision making under uncertainty is to work with combinations or portfolios of options, to address future outcomes. This requires a move away from discrete choices on the preferred option (ranked) which is a central part of the CEA framework. This is a problem for the application of the CEA technique to adaptation.

[4] Cost-effectives can work with multiple metrics, and undertake least cost-optimisation across a suite of attributes. An example this has been adopted in recent European air quality policy, with optimization across a range of different impacts (health, ecosystems, etc.) for different pollutants (e.g. PM, SO2, etc.) has been undertaken (multi-pollutant, multi-effect analysis. However, the key issue here is that the user has to set these criteria., i.e. the analysis is still a relative one, and further, the analytical assessment becomes very complex requiring least cost optimisation models.

2.9 Attribution and Additionality

There are complex issues of the attribution of options, separating out the benefits of options in reducing current climate variability (and the adaptation deficit) versus future climate change, and also the future benefits in relation to climate change compared to those benefits which address underlying socio-economic change.

2.10 Summary of Issues

In summary, whilst the concept of cost-effective analysis is of interest for adaptation, assessing this in practice will involve some challenges.

The sections above highlight that the transfer of cost-effectiveness analysis to the adaptation domain is not always simple, and examples may vary on a case by case basis. The use of this tool will therefore not achieve the same cross-sectoral clarity and comparison as has been possible in the mitigation domain – not least because it is not applicable to economy wide cost curves, because of the lack of common metrics.

Nonetheless, the approach does have potential, not least in terms of a sectorally based systematic comparison of adaptation options in terms of cost-effectiveness.

Considering the issues above, the following recommendations are made (for Mediation).

- The application of cost-effectiveness to adaptation will need to be context and location specific (whilst noting it can be used at relatively aggregated scales). This fits with the Mediation case study approach, and therefore it will be possible to capture these issues with the case studies. However, the analysis will vary with the aggregation level and objectives, and this does raise some issues on how to capture this range of possible uses on the common platform.

- The cost-effectiveness assessments will need to capture sector or even risk specific metrics for analysis. Therefore, each case study will need to select context specific metrics or threshold to allow cost-effectiveness assessment. A later chapter proposes the possible metrics. Again, this raises some issues for the common platform, though a list of possible metrics by sector might be a useful addition to the platform.

- The application of CEA to adaptation will require consideration of technical and non-technical options (also often termed structural and non-structural). The case studies should seek to ensure that soft options and even building capacity are included in the list of potential options. This should also feed through to the common platform, ensuring these options are listed, and potential some examples or case studies on how to assess costs and effectiveness for these.

- Cost-effectiveness analysis will require baselines, which will vary on a case by case, according to starting conditions and existing and planned policy. The case studies will need to capture these issues. This is strongly linked to the choice of socio-economic scenarios, but also extends to the consideration of local policy. This makes the analysis more resource intensive but also more grounded in policy decisions. These factors will need to be captured in the wider guidance on the common platform. A further issue is on the potential for autonomous adaptation. It will be useful (potentially essential) for the case studies to consider the possible autonomous adaptation responses, preferable in a form of the baseline, but if not, as options. Similarly, the consideration of autonomous adaptation is an issue for the guidance on the common platform. A further issue that warrants attention, but may be difficult to analyse quantitatively, is the consideration of adaptive capacity, and how this affects the effectiveness of options.

- CEA for adaptation will have to deal with the problem of uncertainty. The case studies are planning to sample the uncertainty across socio-economic scenarios and climate projections, and need to feed through to the cost-effectiveness analysis. The case studies provide a useful way of testing different approaches for capturing uncertainty within CEA, and avoiding the use of single central projections, thus it is likely that they will need to undertake several assessments, to see how cost-effectiveness varies across the range of possible outcomes. These issues also need to be captured in the common platform, and the case studies could provide examples to help this.

- There is a key issue of what time periods to consider, given the results are time dependent. A good starting point would be to consider the cost-effectiveness of current measures for current climate variability / vulnerability, and then look to assess the cost-effectiveness in a number of defined future periods. To capture the issues of timing and dependencies and adaptive management, it is recommended a minimum of two future time periods are considered, e.g. the 2020s and the 2050s. This would provide some useful case study examples for the common platform.

- There is a need to capture multiple attributes and cross-sectoral effects. For the case studies, it is likely that a single headline indicator (a single metric) will be used, but it will be essential to consider the other potential impacts and whether adaptation options have beneficial effects in addressing these. A further approach might be to consider altering the ranking of options to take account of the various benefits and cross-sectoral issues. This should also include a consideration of whether options have positive or negative effects on GHG emissions. These issues are also important for the common platform.

- The use of a decision making under uncertainty framework is needed for adaptation, and challenging for CEA. The case studies could explore this through the recommendations above (current and several future time periods, multiple scenarios, as wide a range of options as possible, etc.) and these would provide useful examples for the common platform. However, not all aspects of uncertainty and adaptive management can be adequately captured by CEA, and this should be stressed in the case studies and in the platform.

3. Methodological Issues with Cost-Effectiveness Analysis and Cost Curves: Lessons from Mitigation

The use of cost-effectiveness for mitigation has progressed rapidly over the past five years.

The tool has been used extensively in policy support, for example, in relation to carbon budgets for the UK (CCC, 2008) as well as in Europe. It has also been used extensively in the consideration of emission reductions in developing countries (see SEI, 2009).

While this has been useful in promoting the application of this technique, it has also revealed a number of issues that are key to the appropriate use and understanding of cost-effectiveness results, and that have been the source of debate in the literature.

This chapter discusses these issues, then examines the potential relevance for the application of cost-effectiveness to adaptation, and summarises any lessons on how to address these.

3.1 Expert versus Model Based

According to the underlying methodology, MAC curves can be divided into expert-based and model-derived curves. Simply put, expert-based MAC curves assess the cost and reduction potential of each single abatement measure, while model-derived curves are based on the calculation of partial- or general-equilibrium models, as set out in the table below

Model type	**Focus**	**Strengths**	**Weakness**
IAM	Long term costs and benefits of climate change at global level	Impact on the environment, e.g. temperature increase for climate change. Feedback on the economy through damage function (when macroeconomic)	Simplified sector / technology detail, and economic mechanisms (e.g. production function)
Macroeconomic			
Econometric	ST dynamics / costs of adjustment	Economy wide impacts, often at national level ('top-down')	Less detail at mitigation technology level with focus on coverage of economic sectors, and associated impacts
Gen. Equilibrium	LT analysis with the focus on equilibrium after all adjustments	Economy wide impacts, often at national or global level ('top-down')	
Partial equilibrium*	Energy system analyses, focus on short or long term	Bottom-up, technology rich, providing insights on technology pathways / costs. Integrated approach across sectors and demand / supply.	Limited consideration of wider economic effects, or distributional impacts

Energy system models (broadly categorised under the *partial equilibrium* category*)* can be further broken down into optimisation models (such as MARKAL-TIMES) and simulation models (LEAP). Simulation models are primarily accounting frameworks which usefully show the costs of different pathways. They do not cost-optimise and derive minimum cost solutions. Such models are often easier to set up.

Optimisation models solve for the least cost solution so are extremely useful for exploring the cost-optimal means of meeting a climate target (or provision of energy services). They are usually integrated across the energy system, capturing trade-offs between upstream and demand sectors. They are however more difficult to operate and maintain than other approaches.

In the context of adaptation, much of the discussion has centred around the use of expert based analysis. In theory, it would be possible to undertake similar modelling analysis, but this would require the development or extension of models.

3.2 Top-Down versus Bottom-up

There are wide differences in the estimated costs of mitigation between countries and sectors (e.g. Barker et al, 2002 report order of magnitude differences between estimates for mitigation costs curves) and these are often 'real' differences, due to differences in energy structures and the 'no regrets' opportunities available (e.g. energy efficiency investments which save money in their own right, even without considering the avoided climate change damages).

However differences can also be due to the way costs are estimated and modelled. As highlighted by Barker et al, 2007 in AR4, WGIII, these include two broad types of approaches:

- Bottom-up studies, which are based on mitigation options, and have detailed considerations of specific technologies and regulations, but do not consider wider macro-economic effects. They are particularly useful for the assessment of options at a sectoral level.
- Top-down studies, which assess the economy-wide effects of mitigation options. These capture macro-economic and market feedbacks but tend to have less detail on specific technological options. They are particularly useful in informing on cross-sectoral and economy-wide effects.

Much of the available information has primarily been on the assessment of sector-based technical opportunities rather than wider assessment of the impacts on growth, i.e. primarily bottom up studies. These lead to outputs that tend to use an environment / technology cost perspective, rather than from an economic development viewpoint. Certain growth trajectories are assumed, and the reports assess how mitigation will increase overall costs to the economy (i.e. will the additional technology costs be economically disruptive). Analysis of traditional growth drivers – innovation, employment, new markets - tends to get much more cursory coverage in the reports. These aspects are captured by the second set of models.

However, there is a merging of the two domains, either through integrating models together (e.g. as in the EU studies which combine a suite of models and link the outputs) or through hybrid models, for example where top-down models incorporate technological options, or bottom up models incorporate macroeconomic aspects (e.g. MARKAL-Macro), etc. These models are used to construct cost curves by identifying all the expected abatement opportunities for a particular time period in order of cost-effectiveness, and representing their cumulative abatement potential.

In the context of adaptation, most current analysis is constrained to the bottom-up type analysis: there is some early work on the incorporation of adaptation costs in general equilibrium models (e.g. as with Bosello et al, 2007: and additional work for coasts), but this does not reflect anywhere the level of detailed needed to replicate the top-down macro-economic work on mitigation costs.

3.3 Ancillary benefits and Net Cost-Effectiveness Analysis

Mitigation has a number of ancillary benefits, notably in reducing air pollution, and often providing other benefits such as energy security. These often enhance the positive aspects of mitigation, but they are not included in the cost curves, thus there is a potential bias in underestimating the full societal benefits of these measures. Failure to fully quantify them may result in governments underestimating the net benefits of low carbon transition.

Some models (e.g. MARKAL) do allow the use of multiple objectives or criteria, and this can be used to solve a complex multi-attribute optimisation, e.g. where the model selects the least cost solution to hit carbon targets and other constraints imposed: however, this requires complex models.

Some of the recent work in the UK on cost-effectiveness analysis has introduced a new concept (which we term here the 'net cost-effectiveness'), which attempts to bring certain elements of cost-benefit analysis to a MAC assessment, i.e. to try and bring these ancillary benefits into the CEA framework in economic terms. This has even been used in the UK's previous guidance marginal abatement cost assessment by Defra (2006). This introduces adjustments to the CEA analysis to take account of non-carbon benefits, i.e. it adopts a different definition of CEA as

Cost effectiveness = NPV costs less NPV [ancillary] benefits divided by carbon saved.

An example is with the use of economic estimates for air quality (costs or benefits), i.e. as available in the UK (IGCB, 2009, based on Watkiss et al, 2006), which are used to adjust the cost-effectiveness of options. However, this approach is controversial, and seen by many to be problematic, because it merges frameworks and cost estimates in ways that are unlikely to be consistent.

<u>In the context of adaptation</u>, this is a key issue, because many options have wider costs and benefits. This limits the application of cost-effectiveness alone, and thus any application of CEA to adaptation will need to consider how to integrate these wider issues.

For adaptation, this also includes synergies and conflicts with mitigation (GHG emissions).

3.4 Discount Rates

A key issue in the cost-effectiveness analysis is the discount rate is used, i.e. whether a social discount rate (e.g. a value of 3.5% is used in the UK for economic appraisal, though this declines in the longer term [HMT, 2007], while a value of 4% is generally used in EC impact assessment, EC, 2005) or a private sector discount rate (e.g. 10 – 15%) is used. The choice of discount rate can have a large effect on the relative attractiveness of different options, but also shifts the overall cost curve. Note that while there are harmonized social discount rates used in EC economic appraisal, there are not harmonised rates in use across Member states, which potentially is an issue for regional case studies.

Most MACC analyses tend to use low rates, representing Government perspectives, not a commercial outlook. The use of lower discount rate represents a 'societal view' of costs and benefits, highlighting the measures that will be in the public interest to implement.

A private sector perspective can be quite different, with investment decisions factoring in much higher rates. Higher rates make options with high upfront costs and future streams of benefits (e.g. many energy efficiency investments) appear less attractive. This moves the MACC upwards, and changes the order of options on the basis of cost-effectiveness. Conversely, a low rate will make such options more attractive.

This is particularly important when thinking about who will be making investments in different sectors and expected rates of return and investment risk accepted.

In the context of adaptation, the discussion of discount rates is also valid, though in the case of planned adaptation, the consideration will be primarily based on government social discount rates, consistent with policy appraisal practices in Member States and the Commission. However, a simple way to address this issue is by including sensitivity analysis, to look at the change in the MACC curves with alternative societal and private rates.

For adaptation, the choice of discount rates is very important in relation to potential long-term measures, to address potentially large-scale risks. This is an area that warrants further consideration.

3.5 Technical versus Policy Costs (Transaction Costs)

Most cost curves do not include the costs of implementation, as they are generally concerned with technical costs divorced from the type of policy used for implementation. They therefore do not fully reflect high costs policy and transaction costs associated with options. Often such costs are highest for those measures which appear most cost-effective. Barriers are discussed although their non-representation in the financial analysis is problematic, often resulting in a more optimistic outlook than might reasonably be expected.

Indeed, recent studies have reported that implementation can have significant costs. These include the costs of administering a policy but also the transaction costs associated with different options. Two studies from the UK, Enviros (2006) and Ecofys (2009) highlight this issue. Ecofys (2009) suggests that hidden costs not usually captured in financial analysis can significantly increase the payback period for selected household energy efficiency measures. Enviros (2006) analysis suggests that the inclusion in the analysis of additional hidden and missing costs can reduce cost-effective opportunities by between 10-30% in the buildings sector. At the broader level, McKinsey (2009) estimate a range of €1-5/tCO_2e for such costs, which can be significant, particularly when average abatement costs are very low (or even no regret).

Effective policy measures are difficult to design and implement, and often require financial incentives which add to costs. The fact that significant energy efficiency opportunities still exist in many developed countries many years after strategies introduced to address GHG emissions reinforces this point.

In practice, costs associated with the individual mitigation options are likely to be higher than those in the studies reviewed due to significant implementation challenges relating to the scale and timing of envisaged measures. All of the studies base their economic assessment on the timely implementation (at zero implementation cost) of all measures identified. Experience would suggest that this is unlikely, with many market participants failing to pursue activities that are otherwise economically rational. A failure to appreciate implementation costs up front may result in governments underestimating the costs of delivery, particular for sectors where such delivery costs may be large in relation to the technology costs.

In particular, the dynamics of consumer response in relation to market based incentives is an area that is poorly understood, and an environmental technology cost analysis may not provide a fair reflection of likely policy outcomes. This is especially true of energy efficiency improvements, which provide a large proportion of negative and low cost measures in the MAC curves, but which many governments have struggled to implement in an effective way.

More work needs to be undertaken to incorporate these barriers into cost-effectiveness analysis, to provide more realistic assessments of the actual costs of realising potential across different sectors.

In the context of adaptation, this is another key issue, because of the need to adequately capture the full costs of options, rather than only assessing the technology costs. However, it should be possible to build in estimates (or sensitivities) for these.

3.6 Baseline, including Technology and Reference Costs

A key issue for cost-effectiveness is the reference or standard case (or technology) that is used in the business as usual case. This forms the basis against which the option is appraised. The choice of this reference case therefore has a very large effect on the cost-effectiveness of the option.

A further issue here is the cost assessment of the baseline, e.g. whether current household fuel prices are based on retail prices (including or excluding all taxes), or whether road transport fuels do or do not include taxes (e.g. to enable comparison with biofuel production costs).

At the wider level, there is also a need to consider what is included or excluded within the baseline, consistent with normal policy appraisal. As an example, this will include existing policies or measures.

All of these aspects are important because they significantly impact on what can be assumed for mitigation potential and with respect to measure inclusion, what is additional.

In the context of adaptation, the derivation of the baseline case could be challenging. In areas such as energy, it will face similar issue to the energy mitigation analysis, however, similar aspects will also be relevant in other sectors.

The wider issue of the policy baseline is perhaps even more complex, because there will be a need to build in existing measures – either that are addressing current vulnerability – or introduced to start preparing for future climate change. As example, cost-effectiveness analysis of flood measures for future climate change has to build a baseline around existing defence and levels of protection. Similarly, future assessments of heat related mortality need to take account of the effectiveness of current heat alert systems to deal with future climate change. These baseline assessments are location specific (be that at Member state down to local level).

3.7 Uncertainty (Cost and Overall Estimates)

The representation of the MAC curve in previous chapters suggests that costs are known accurately for any given level of emissions reduction.

Clearly, in practice this is not always the case, and uncertainty in costs is an important issue to consider. Previous studies have highlighted the uncertainties in MAC estimates (notably for longer-term emission reductions, see Barker et al, 2002; Watkiss et al, 2006, etc.). There is a wider literature on the estimates of ex post out-turns, which shows wide ranges from anticipated ex ante estimates, though for environmental policies, these often show lower costs than anticipated (Watkiss et al, 2003).

It is also important to recognise that there is uncertainty over policy implementation (i.e. whether measures are realistic).

Across most studies to date, there is a limited uncertainty and sensitivity analysis. Indeed, MACC are particularly bad in nearly always providing a single central output (one curve).

Most of the studies do not present (transparently at least) the range of baselines, costs, etc. from key assumptions in relation to growth, oil and energy prices, population growth, discount rate etc.

MAC curves should ideally include ranges of costs rather than point estimates in order to inform a risk-based approach to decision making, and should take account of realistic policy outcomes (i.e. to prevent potential risks to credibility and confidence from setting targets that cannot subsequently be achieved).

In UK mitigation analysis, there has been a tendency to move away from a single centralised baseline but rather have a number of baselines based on different assumptions (fuel prices, economic growth, and discount rate). This provides ranges rather than single estimates, and highlights the uncertainties that may be hidden in core assumptions. In addition to sensitivity analysis, no mitigation assessments undertook any uncertainty analysis around technology learning or availability of an emerging / new technology. Current UK modelling analysis is increasingly taking account of the cost of uncertainties associated for example with technology failure e.g. CCS or missed targets, using stochastic techniques.

In the context of adaptation, this is another key issue. There is often poor information on the costs of adaptation, especially as applied to the future effects of climate change. Moreover, many of the promising early adaptation options involve building adaptive capacity, which is often difficult to estimate in cost terms, or non-technical options, that are much more challenge to assess than technical options. A key focus is therefore to expand the cost estimates for these options.

Furthermore, there is a need to build wider uncertainty into the cost-effectiveness analysis of adaptation. The presentation of single central curves is considered particularly inappropriate for adaptation, given the underlying uncertainty.

3.8 Underlying Assumptions

Another related issue relates to future projections, as these determine cost-effectiveness values going forward. For example, for mitigation, the metric of cost-effectiveness is particularly sensitive to fuel prices, and in the longer term, these are very uncertain.

In the long run, technology price and efficiency changes remain an unknown, with potential for both upside and downside against projections.

In the context of adaptation, especially given the long-time frames, it will be important to examine the key assumptions that affect the cost-effectiveness. This may include determinants of future socio-economic change (e.g. population, income) but also may involve future socio-economic scenarios related to future worlds (e.g. business as usual versus sustainable). Similarly, there will be issues where relevant future prices (e.g. fuel prices, water, etc.) will add extra uncertainty to the analysis of adaptation.

Importantly, it also includes the assumptions about the level of autonomous adaptation, which will affect the relative cost-effectiveness of future planned adaptation options. Note also that this links strongly with adaptive capacity, i.e. the future MAC for adaptation is a function of the level of adaptive capacity over time.

3.9 Linkages, Feed-backs and Interactions

Most MACC assessments have limited feedback between sectors. Indeed, integrated system modellers often cite the lack of interaction between sectors as a significant problem with MACCs.

As an example, in an energy system, what happens in one sector might impact on electricity demand which in turn affects the upstream sectors. None, or at least very little of this is captured in MACC analysis (though some MACC analyses do account for changes in electricity sector intensity).

An associated issue is the interaction between measures. Introducing one measure first could have an impact on the cost-effectiveness of the second measure and so on. This may be particularly true of building measures. (Note that such interactions are sometimes captured in model-derived MACCs).

MACCs often take account of overlaps between the ranges of alternative options but not always. A MACC may list three power plant options; however, if one is introduced it may be the case that the other two are not needed. Therefore simply aggregating options in a MACC to get total potential is not always correct.

In the context of adaptation, this is likely to be an issue, especially for some sectors that have wider cross-sectoral relevance, an example being in relation to the water sector and multi-functionality of water resources. However, tackling these issues is complex.

3.10 Timing and year of implementation

Cost-effectiveness analysis is time specific. When MAC curves are presented, they are defined with respect to a certain year, e.g. 2010, 2020, 2030, etc.

This is important, as the options and cost-effectiveness will vary with the year chosen, because of the baseline rates, the assumptions about learning, etc.

It also leads to issues of how to provide linked cost curves that integrate and update with measures from earlier periods, noting this will affect the shape of future curves, as well as highlighting issues of inter-dependencies, conflicts and synergies between options in different time periods, etc.

Furthermore, cost-effectiveness assessments are static snapshots of mitigation potential in a given year. Therefore, they are of limited benefit in helping understand when investments should occur, for example, or whether additional options will be available in subsequent years. If a MACC time series is available, care is then needed to ensure that the baseline in subsequent years is adjusted to account for any additional take-up of measures.

Most of the studies have a short timeframe, mainly to 2030. A 2030 timeframe can be problematic because post-2030 emissions may still be rising and further mitigation options (which will be higher costs e.g. further up the cost curve) may be required to sustain stabilisation pathways.

Most MACC studies consider fully commercial technology options. It may be that emerging technologies that are commercially available in 2020 / 2030 offer better longer term investment choices.

Failure to consider the potential linkage between the medium term (2030) and the longer term (2050), may result in lock-in to technologies that are not low carbon or from an optimisation point of view, investment in technologies too early e.g. before the benefits of technology learning are realised. In addition, technologies such as CCS may well be commercially available around 2030 but not taken up because of a short analysis timeframe. The shorter timescale also means a much greater focus on energy efficiency measures.

Cost curves that are populated by technology-rich bottom up models may struggle to identify long-term abatement options, so that analysis of cost-effectiveness of 2050 targets may require different model approaches than analysis of interim targets.

The UK recently went through the process of thinking about shorter term (2020) versus longer term targets (2050) and the potential to lock-in investment due to short sightedness as it proposed carbon budgets (CCC, 2008). It suggested that costs could be significantly higher if the wrong investments were made without consideration of longer term targets, particularly for high capital measures with a long lifetime e.g. power stations.

In summary, there are two key issues with the use of analysis timeframes that are too short. First, it underestimates the longer term challenge, both in terms of required reductions and costs and second, it risks of non-optimal investment and technology lock-in increase.

In the context of adaptation, there is a particular need to consider the time domain for adaptation, i.e. what future years the cost-effectiveness analysis should be undertaken for. This is particularly challenging because of the need to implement adaptation proactively to address future impacts of climate change. There is also a need to understand the longer term climate issues, and the risks of lock-in and option values in deriving adaptation cost curves.

3.11 Learning Curves and Innovation

The actual costs of mitigation depend not only on modelling assumptions, but also on the efficiency and nature of the policies adopted, and the extent of technological innovation achieved. The rate of low carbon growth is as much dependent on the pace of technological innovation (operating efficiencies) as it is on macro-economic policy.

This issue is the subject of a major debate over how the costs of new and advanced technologies decrease over time. This involves the assumptions about technology learning rates and learning curves[5].

As an example, renewable generation costs have generally fallen as these new technologies have been developed and entered into the mainstream of electricity generation over the past two decades. A key part influence on CEA is whether the costs of such technologies will continue to fall, or whether, as they mature, the scope for further cost reductions and experience will reduce. Similar issue arise with new or developing technologies. As well as learning, cost reductions occur due to a far broader range of factors, including technological change, availability and constraints, etc.

This sits within a wider debate on innovation and emission cuts, i.e. on endogenous technical change and how to induce this, and whether it is more efficient to channel efforts

[5] The learning curve concept originally arose for manufacturing and assembly tasks, with the premise that each time the product quantity doubles the resources (labour hours) required to produce the product would reduce, the % of which is the learning curve slope. This can be used to plot cost reduction curves. There are historical rates observed for some low carbon technologies, e.g. introduction of renewables notably wind, which show steep reductions in costs, particularly from early years. However, these have been criticised because they are generally based on abstract extrapolation, rather than engineering insight.

into R&D in the short term and undertake more rapid abatement once cheaper low-carbon technologies, have emerged, or whether endogenous technical change occurs through learning-by-doing, which implies that the costs of low-carbon technologies only fall with actual deployment or experience/learning.

In the context of adaptation, the issues of learning and innovation are relevant for adaptation cost curves, because they will affect future costs of newer ‘adaptation’ technologies, and because there will also be a similar issue whether technical change for adaptation is best advanced through R&D or through deployment.

3.12 Summary

This section highlights a number of additional issues that could be relevant for the application of CEA to the adaptation domain. While many of these are complex, and are arising and being addressed in second generation CEA analysis for mitigation, it is useful to consider and learn from them in the context of adaptation.

4. Possible Sector CEA Metrics for Adaptation

The potential for cost-effective metrics and application into cost-effectiveness analysis is reviewed below by sector, drawing on the literature in this area, expanding previous work (Markandya, 2009: Watkiss et al, 2009; UNFCCC, 2009).

4.1 Health

The application of cost-effectiveness requires common metrics. These exist for the health sector in the form of fatalities (Deaths) but even more so through the metric of Disability Adjusted Life Years (DALYs). The Disability-Adjusted Life Year (DALY) is a measure of overall disease burden, combing information on mortality and morbidity into a single comparable measure, and thus providing a common metric to allow cost-effectiveness analysis. The DALY is based on years of life lost from premature death and years of life lived in less than full health, see box.

Disability Adjusted Life Years

A DALY can be thought of as one lost year of "healthy" life. The sum of these DALYs across the population, or the burden of disease, can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability.

DALYs for a disease or health condition are calculated as the sum of the Years of Life Lost (YLL) due to premature mortality in the population and the Years Lost due to Disability (YLD) for incident cases of the health condition, i.e. DALY = YLL + YLD:

The YLL basically correspond to the number of deaths multiplied by the standard life expectancy at the age at which death occurs. The basic formula for YLL (without yet including other social preferences discussed below), is the following for a given cause, age and sex: YLL = N + L
Where N = number of deaths and L = standard life expectancy at age of death in years

Because YLL measure the incident stream of lost years of life due to deaths, an incidence perspective is also taken for the calculation of YLD. To estimate YLD for a particular cause in a particular time period, the number of incident cases in that period is multiplied by the average duration of the disease and a weight factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (dead). The basic formula for YLD is the following (again, without applying social preferences): YLD = I x DW x L
where: I = number of incident cases, DW = disability weight, L = average duration of the case until remission or death (years

There are some issues with the use of these values, as egalitarian principles are explicitly built into the Disability-Adjusted Live Year (DALY) metric, and the global burden of disease applies these to all regions of the world. The studies use the same "ideal" life expectancy for all population subgroups and exclude all non-health characteristics (such as race, socioeconomic status or occupation) apart from age and sex from consideration in calculating lost years of healthy life. Most importantly, they use the same "disability weight" for everyone living a year in a specified health state.

A disability weight is a weight factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (equivalent to death). Years Lost due to Disability (YLD) are calculated by multiplying the incident cases by duration and disability weight for the condition. Disability weights were used for the GBD 2004.

Finally, there is often age weighting and discounting applied. A 3% discounting and non-uniform age weighting was used in the original GBD 1990 study. These adjustments result in less weight given to years lived at young and older ages. The GBD 2001-2 study used 3% discounting but uniform age weighting. The latest GBD 2004 update used the original 3% discounting and non-uniform age weighting.

Source : Reproduced from WHO
http://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/index.html
http://www.who.int/healthinfo/global_burden_disease/daly_disability_weight/en/index.html

It has been used extensively in the WHO global burden of disease studies, which look at mortality and burden of disease attributable to numerous global risk factors using a consistent analytic framework known as Comparative Risk Factor Assessment. This includes assessment of climate change (McMichael, et al, 2004).

In turn, a number of studies have combined estimates of these future DALYs (from climate change) with the cost of adaptation, generally drawing on the underlying literature on the cost-effectiveness of health options in terms of health prevention costs (Ebi, 2008; Markandya and Chiabai, 2009).

Cost-effectiveness

The use of DALYs provides an easy common metric to undertake cost-effectiveness analysis in the health sector.

There have also been some explicit examples of the cost-effectiveness for health and climate change. The Economics of Climate Adaptation Working Group (ECA, 2009) undertook case studies. While the study primarily used cost-benefit analysis, presenting this in terms of marginal NPV curves, it did undertake an example on health adaptation in Tanzania using cost-effectiveness, and built up a cost curve, looking at drought related health impacts.

As highlighted in the introductory sector in an earlier chapter, the UK National Institute for Public Health and Clinical Excellence (NICE) uses a similar measure, the QALY (quality adjusted life year) and uses cost-effectiveness analysis to assess new drugs or treatments, using a threshold value of £20,000 – 30,000 to assess whether these are cost-effective. In theory, a similar approach and threshold could be used to assess whether health interventions for climate change represented value for money.

Note, however, that there are some issues, namely as DALY are often discounted, which leads to issues in the application to cost curves (making sure not to double discount). Furthermore, it can be difficult to express some health endpoints in DALY – they are primarily based for disease outcomes associated with public health.

There are additional issues of occupational health, which require different approaches. In some cases, suitable occupational thresholds exist to allow assessments, for example, there are occupational exposure limits to high temperatures in the workplace.

Further, there are some issues in other areas related to cross sectoral impacts, which may require the analysis of health impacts in ways which are more consistent with the underlying sectoral impacts, or where there is a need to combine impacts across sectors. An example is for flood risk, where secondary effects on well-being (psychological illness such as depression) from floods are an important issue. While there are some health care measures that could be assessed to cope with these potential health impacts, the primary adaptation measure would be flood prevention (defence, etc.), which would be primarily assessed within the flood sector analysis.

Example of Cost-Effectiveness for health

The study identified drought-related health impacts as: malnutrition, trachoma (an infectious eye disease that causes blindness), dysentery, cholera, and diarrhoea. While recognizing that many factors drive disease prevalence and occurrence, the study focused on isolating a single driver. It correlated historical rainfall data with historical numbers of cases of key diseases and with crop supply and demand imbalances (as a proxy for malnutrition). This analysis allowed a prediction of the additional number of people affected by those diseases in the future (albeit simply, without assumptions of changes in development, baseline rates, etc.), linked to assumed changes in drought frequency and severity (again, without any socio-economic changes).

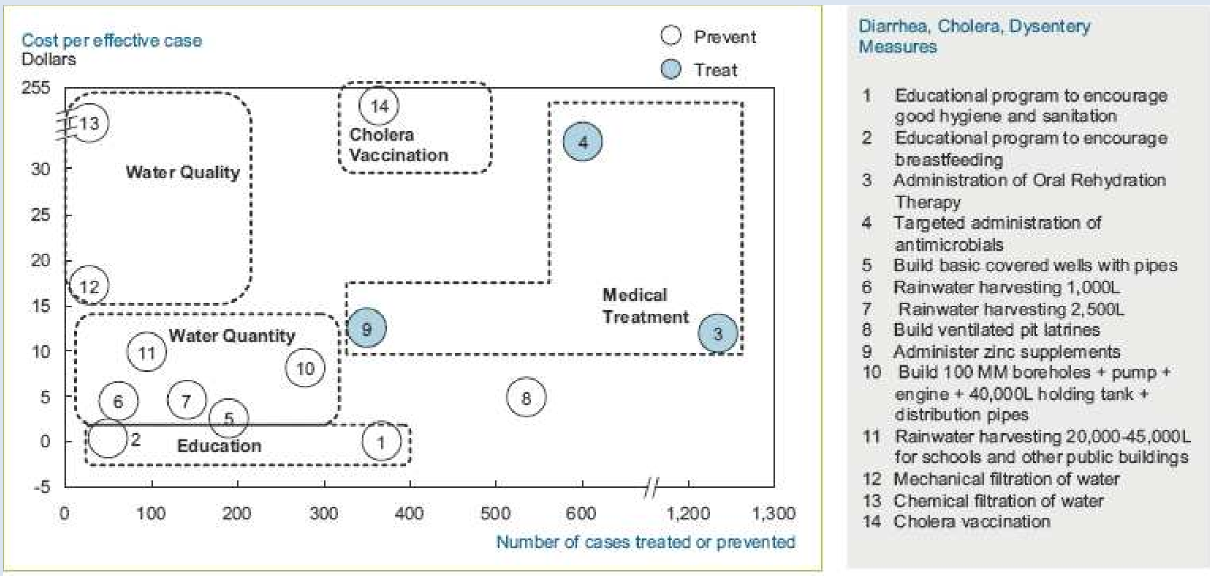
The study estimated that by 2030, under the moderate climate change scenario, a 10 percent decrease in average rainfall was projected to cause a 60 percent increase in the proportion of the population under food stress, and significant increases in the number of cases of cholera and dysentery. Trachoma cases were estimated to potentially double in number. The high climate change scenario would worsen this impact.

The study analysed measures to protect against drought-related health risks cases. Measures were classified as prevention (such as cholera vaccinations) or treatment (such as oral rehydration therapy for cholera patients). The costs of each measure were estimated, including the costs of various components of the programme and the likely efficacy of the intervention.

Costs of medication included purchase, shipping, storage and distribution of storage, as well as the overhead costs such as training and salaries.

The estimated disease burden that would be prevented with each measure was estimated, discounted by the penetration rate - the proportion of the population that could be reached - and the efficacy rate (%). Applying this information, the study ranked a number of potential strategies on the basis of cost per effective case. The study found the educational programmes and water quality improvements (rainwater harvesting) were highly cost effective measures, as shown in the figure below.

Cost-effectiveness ranking of alternative measures to reduce climate change-related health impacts in Tanzania.



Source ECA, 2009.

Note that there are many methodological issues with this study, notably the use of global general circulation models to predict extreme events (droughts) at the sub-national level in the year 2030, issues on how the baseline impacts were assessed and projected (the study did not take account of future development, thus translated historical incidence to the future without accounting for interim development) and finally on how the benefits of individual measures were assessed in reducing impacts from extreme events. Nonetheless, it provides a useful example of the CEA application for health including indicative cost curves.

4.2 Flooding including river, coastal and intra-urban flooding

While flooding involves a set of common impacts, there are important differences between coastal, riverine and intra-urban flooding. This means these three areas need to be considered separately. In each case, possible common metrics and cost-effectiveness analysis is possible, and indeed, this is one area where the CEA approach is already widely applied.

Coastal
Climate change is likely to have significant impacts on coastal zones, particularly via sea-level rise and changes in the frequency and/or intensity of extreme weather events, such as storms and associated storm surges. The direct impacts include inundation and displacement of wetlands, lowlands, coastal erosion, increased storm flooding and damage, increased salinity in estuaries and coastal aquifers, and rising coastal water tables and impeded drainage. Potential indirect impacts include changes in the distribution of bottom sediments, changes in the functions of coastal ecosystems and impacts on human activities.

The range of possible impacts and the wide range of receptors (people, property, ecosystems, etc.) actually make it more challenging to apply cost-effectiveness. A key issue is whether there are potential common metrics that can be used – or whether there are appropriate headline indicators that can be used a measure of the overall issue.

In many assessments, the common metric of flood risk to people is used, primarily in the context of acceptable flood risk levels. Such an approach has been used commonly in the UK and the Netherlands (see later). However, in the wider context of sea level rise it is useful to examine whether this is the appropriate metric.

The OECD undertook an expert exercise to investigate this (Nicholls et al, 2006: Metrics for Assessing the Economic Benefits of Climate Change Policies: Sea Level Rise). It reported a range of metrics, reflecting the range of potential effects of sea level rise that highlighted the wide range of potential metrics, and also the potential for cross-sectoral impacts (e.g. losses to agriculture sector, infrastructure, etc.). It also highlighted that there are more wide ranging metrics associated with major sea level rise, i.e. post 2100 and with the potential for onset of irreversible melting of the Greenland ice-sheet or break off of the West Antarctic ice-sheet.

The analysis identified key effects and adaptation responses from sea level rise, as shown in the table below.

Table 1. **The five major natural system effects of relative sea-level rise, including examples of possible adaptation responses (NICHOLLS, 2002; NICHOLLS and TOL, accepted). The possible adaptation responses are defined as [P] – Protection; [A] – Accommodation; and [R] – Retreat (see Table 3).**

NATURAL SYSTEM EFFECT		POSSIBLE ADAPTATION RESPONSES
Inundation, flood and storm damage	a. Surge(sea)	Dikes/surge barriers [P], Building codes/floodwise buildings [A], Land use planning/hazard delineation [A/R].
	b. Backwater effect (river)	
Wetland loss (and change)		Land use planning [A/R], Managed realignment/ forbid hard defences [A/R], Nourishment/sediment management [P].
Erosion (direct and indirect morphological change)		Coast defences [P], Nourishment [P], Building setbacks [R].
Saltwater Intrusion	a. Surface Waters	Saltwater intrusion barriers [P], Change water abstraction [A/R].
	b. Ground-water	Freshwater injection [P], Change water abstraction [A/R].
Rising water tables/ impeded drainage		Upgrade drainage systems [P], Polders [P], Change land use [A], Land use planning/hazard delineation [A/R].

Source: Nicholls et al, 2006

A number of points here emerge that are useful for the general discussion of metrics.

First, there are at least two distinct approaches to develop relevant metrics:

- One is based on exposure metrics. These define areas and associated populations and resources that may be potentially threatened (usually based on present socio-economic characteristics) and can be estimated using a GIS approach (exposure to sea-level rise) with an inventory of assets and resources that are threatened assuming no adaptation.
- The other relates to impact metrics, which aim to estimate actual impacts under different dynamic sea-level and socio-economic scenarios using integrated assessment of both exposure and adaptation decisions based on criteria such as benefit-cost analysis. Starting with estimates of exposure, estimates of residual impacts before and after adaptation are made, as well as the costs of adaptation.

Second, different metrics are relevant in the short to medium term (e.g. 2050) and long-term, especially post 2100, as the latter includes potentially much more important impacts.

Third, there are is a large suite of potential effects, which makes development of a single overarching metric, even within one impact category, extremely challenging.

The study highlighted the challenges in trying to apply these metrics at national level - indeed it concluded that the method was appropriate when applied to well understood systems (e.g., engineered flood defences under sea-level rise), but could not be applied more widely (e.g. an entire country under sea-level rise).

The study provided a set of recommend metrics, for exposure and impacts, shown below.

The work also raised issues of the residual risk, and catastrophic failures even with protection scenarios. It also raised the problems with areas that are typically poorly studied, e.g. salinisation and water supply, as well as tipping point for coastal abandonment and retreat from multiple factors.

Table 6. **Recommended exposure metrics for the impacts of long-term sea-level rise. Note that this list is not comprehensive and other exposure metrics might be defined based on individual needs. Methods to estimate these metrics in conjunction with geographic information system techniques are elaborated in Section 4**

Metric	Units	Comments
Land area at risk	Threatened area (absolute: km2, or relative impact: % available area)	The preferred metric in the Questionnaire (Appendix A3) – can distinguish land above and below high water.
People at risk	Number of people (absolute or relative impact: % population)	Scenario dependent
Ecosystems at risk	Threatened area of ecosystems (km2)	Scenario dependent
Economic value at risk	Monetary value (absolute: monetary value or relative impact: % GDP)	Scenario dependent
Important human infrastructure at risk	Inventory approach (e.g., threatened transport corridors)	Based on existing distribution
Cultural/heritage at risk	Inventory approach (e.g., threatened UNESCO World Heritage sites)	Based on existing distribution
Possible changes in event frequency	Reduction in return period without adaptation (e.g., present 100 year event would have a return period of x years)	Relevance diminishes with increasing magnitude of sea-level rise (submergence increasingly dominates)
Potential rates of change (e.g erosion)	Total shoreline retreat without adaptation (m or km, as appropriate), or rate of retreat (m/yr)	

Table 7. **Recommended impact metrics for the impacts of long-term sea-level rise. Note that this list is not comprehensive and other impact metrics might be defined based on individual needs. Methods to estimate these metrics in conjunction with integrated assessment models are elaborated in Section 4.**

Metric	Units	Comments
Land area loss	Lost area (absolute: km2, or relative impact: % available area)	The preferred metric in the Questionnaire (Appendix A3)
People displacement	Number of people (absolute or relative impact: % population). Cost of displacement(absolute: monetary value or relative impacts: % GDP)	Scenario dependent
Ecosystems loss/change	Threatened area of ecosystems (km2). Cost of losses/changes (absolute: monetary value or relative impacts: % GDP)	Scenario dependent
Economic value loss	Monetary loss (absolute costs in monetary terms or relative costs: % GDP)	Scenario dependent
Human infrastructure loss	Inventory of losses (e.g., list of disrupted transport corridors)	Based on existing distribution
Cultural/heritage loss	Inventory of losses (e.g., list of lost UNESCO World Heritage sites)	Based on existing distribution
Adaptation costs	Monetary cost absolute costs in monetary terms or relative costs: % GDP)	Usually comprise protection – capital and running costs can be distinguished. For protection, related output metrics might include defended length and defence height.
Changes in event frequency	Reduction in return period with adaptation (e.g., present 100 year event would have a return period of x years)	Relevance diminishes with increasing magnitude of sea-level rise (as submergence increasingly dominates), but there may be exceptions.
Rates of change (e.g erosion)	Total shoreline retreat with adaptation (m or km, as appropriate), or rate of retreat (m/yr)	

Source: Nicholls et al, 2006

The study undertook a questionnaire which identified that the preferred metric was land area at risk (as depicted on a map), a simple exposure metric that is economically relevant, and easy to communicate to decision makers and stakeholders. “Land area at risk” is independent of the scenario problems and was seen to contain the base information needed for a wide range of more individual specific analysis. However, an expert workshop also highlighted metrics of exposure and impacts, and also sensitivities, which might be triggers for adaptation action (tipping points for action). These could include triggers for the need to upgrade defences, and are closer to the risk based approaches outlined later or the portfolio or corridor approaches.

The OECD study (above) concluded that the simplest metric was the land area at risk (from SLR). Of course, why this is simple, it does not provide much information on expected damages or specific issues that might be relevant for a particularly project or area.

Working from this, the cost-effectiveness analysis could simply be based on this exposure metric. However, a more useful analysis would be to link the metric to the cost per ha. of the land lost, and therefore to allow a more efficient analysis of adaptation measures relative to the increase in services per ha., e.g. taking market and non-market values for land prices (as a measure of the discounted present value of future land services)[6]. However, even this simple approach has significant problems. This includes land values not captured in prices, and non-monetary values of land associated with e.g. ecosystem services or special or protected sites.

However, while this is a useful combined metric, it would lead to different cost-effectiveness analysis when compared to acceptable flood risk approaches currently in use (e.g. in terms of the ranking of options).

Moreover, as outlined above, land area lost is only one of a large number of possible impacts from SLR. Therefore the use of a single metric for adaptation would only represent a partial coverage of benefits. This is important because it would miss major effects associated with the risk of flooding, and the physical damage from this as well as the socio-economic effects.

This raises some interesting issues, notably how much the choice of metric affects the analysis. One possible area for Mediation to investigate is therefore how much the choice of the effectiveness criteria affects the results.

Applications of cost-effectiveness analysis

Coastal flooding is one of the more comprehensively studied areas for adaptation. Estimates of the costs and benefits under climate change have been made; and in fact this is one of the better quantified areas of impacts (EEA, 2007; OECD, 2008).

At the aggregated scale, the concept of cost-effectiveness is employed in a number of models. The DIVA database and model produced from the DINAS-COASTS DG research project ((DINAS-COAST Consortium, 2006; Hinkel and Klein, 2007; Nicholls et al., 2007; Vafeidis et al., 2008) can assess the potential impacts and economic costs and the costs and benefits of adaptation. Within the model, adaptation is focused on two key areas, beach nourishment, which is assessed using a cost-benefit optimisation, and the costs of protection, which is based around an pre-defined acceptable level of risk, thus effectively undertaking a cost-effectiveness based approach.

There is work in the Netherlands (RIVM, 2004) that looks at the risks of flooding, and works with cost-effectiveness metrics. This also recognises that technical solutions no longer form the sole answer to this increase, with efficient solutions in spatial planning as well as reducing risks of dike breaches by technical means. The Figure 3 (left-hand side) shows the maximum financial-economic value per kilometre of dike as being not necessarily high in the relevant dike-ring areas with a relative high standard. The right-hand side of this figure

[6] In over-simplistic terms, if one is dealing with total loss under climate change, and if the adaptation measure recovers the land to its full extent, one can compare the cost per ha. of the measure against the current price of the land. In more complex cases land may be partially recovered, in which case one has to estimate the value of the partially recovered land and compare it against the adaptation measure.

shows the total set of dike-ring areas distinguished according to the maximum damage per kilometre. The groups are fully mixed and the distinction between the four groups has disappeared. Applying spatial differentiation of safety levels according to potential economic damage can increase policy efficiency.

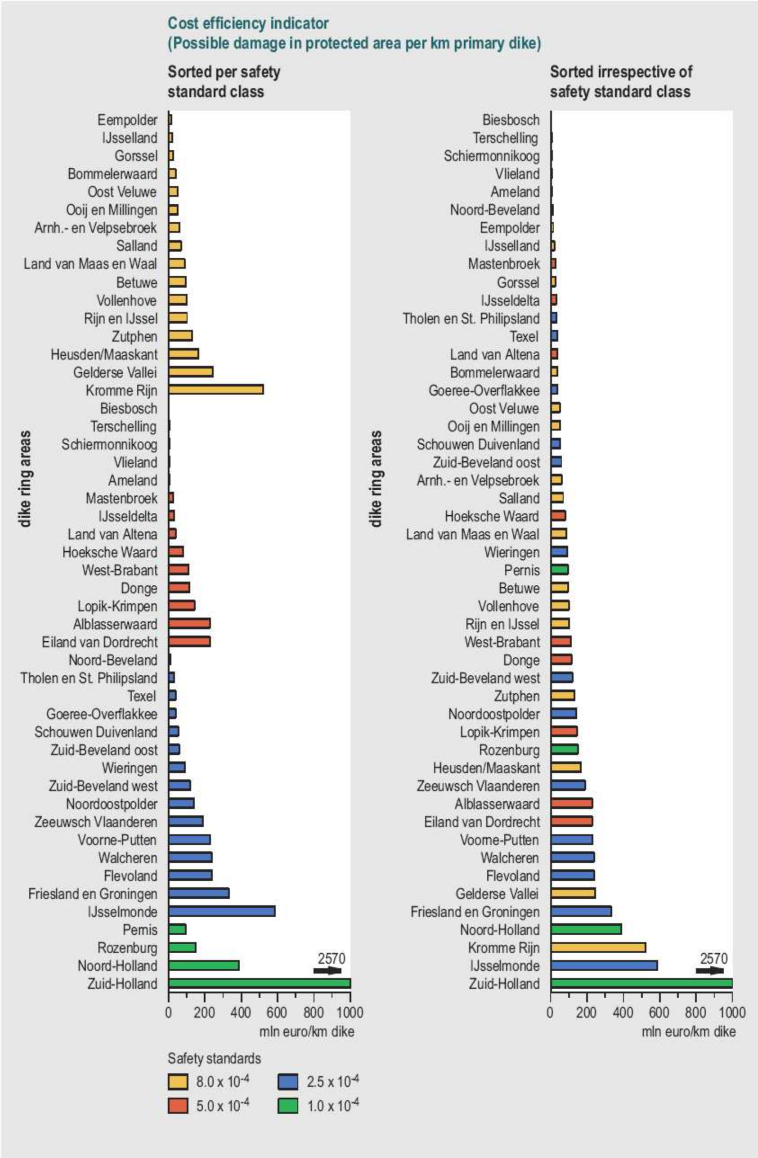


Figure 3 The maximum damage per kilometre of dike for all dike-ring areas for standard (left) and potential damage (right).

Source: RIVM, 2004

This can lead to a comparison of different adaptation options to see which can achieve flood protection standards most cost-effectively (at least cost).

In the international context, the approach has often been used in the context of risk management frameworks, e.g. ADB in the pacific.

One additional issue is that the acceptable levels of protection, i.e. the acceptable flood risks, are not uniform across Europe, thus the cost-effectiveness objective varies. As an example, in many regions of the Netherlands, protection levels are set to a 1 in 10000 year event, whilst in the UK, the broad policy objective (e.g. the design level in the Thames Barrier) is for a 1 in 1000 year event. This means the individual policy context is needed and will vary (e.g. with the case studies but also in reporting this for the common platform). Furthermore, there is no guarantee that these levels of acceptable risks will be maintained going forward, e.g. that these may be changed in light of resource issues or the practicality of maintaining current levels for all.

River and intra-urban flooding
Many of same issues that arise for coastal flooding also arise for river and intra-urban flooding, however, in these cases there is a greater focus on flooding and property damage (especially for intra-urban flooding).

4.3 Agriculture

As with coastal zones, climate change has a wide range of effects on agriculture (more accurately, on agriculture, livestock, horticulture, etc.). The OECD considered metrics for agriculture (OECD, 2007) for analysing the magnitude and timing of climate change impacts. The proposed general framework identified biophysical factors, agricultural system characteristics, socio-economic data, and climate policy as key categories for analysis, and related them to vulnerability criteria of agricultural systems in terms of their exposure, sensitivity, adaptive capacity, and synergy with mitigation strategies under climate change.

Examples of climate change agricultural impacts and responses

System Impact	Possible Adaptation Response
Biomass increase under elevated CO_2	Cultivar selection to maximize yield
Acceleration of maturity due to higher temperature	Cultivar selection with slower maturing type/ crop shifts
Heat stress during flowering and reproduction	Early planting of spring crops
Crop losses due to increased variability Drought/flooding	Crop mixtures/rotation/change in soil and water management; Advanced warning systems
Increased competition/pests	Land and input management/Biotechnology

General framework for agricultural metrics

Categories	Vulnerability Criteria	Measurement Class
Biophysical indicators	Exposure	Soil and climate, Crop calendar, Water availability and storage, Biomass/yield
Agricultural system characteristics	Sensitivity	Land resources, Inputs and technology, Irrigation share, Production
Socio-economic data	Adaptive Capacity	Rural welfare, Poverty and nutrition, Protection and trade, Crop insurance
Climate policy	Synergies of mitigation and adaptation	Kyoto commitment capacity, Regional Support Policy, such as CAP, Carbon sequestration potential, CDM projects in place, planned, Bio-energy, Irrigation Expansion projects, Land expansion plans, Change in rotations/cropping systems

Source: Rosenzweig and Tubiello (2007)

The study produced a set of metrics, comprised of variables that could be easily extracted from current models and used to obtain consistent and comparable information on climate change impacts and benefits in both monetary and non-monetary terms. It focused on the development of metrics for regional, national, and global scales, characterizing the short-term (20-30 years) and long-term (80-100 years) impacts of climate change on agriculture.

The study proposed the following explicit metrics: crop suitability, crop yield and water stress as biophysical indicators; land resources, regional cereal production and water resources as agricultural system characteristics; economic value, land value, and a nutrition index assessing number of people at risk of hunger, as socio-economic indicators; and finally mitigation potential, as a measure of competition and/or synergies between adaptation and mitigation strategies.

The report considered that these metrics focus on key agricultural system characteristics helping to quantify, using both monetary and non-monetary terms, severity of impacts; system capacity to respond to climate change; and adaptation options that minimize risk and/or maximize benefits. Further that they should help national policy-makers and regional planners to assess the vulnerability of agricultural systems to increasing degrees of climate change, and to identify thresholds beyond which current coping capacity and autonomous adaptation should be complemented by planned adaptation responses at local to regional levels, involving significant changes in management practices. The work also highlighted the potential for vulnerability thresholds derived from the impact metrics, as specific values of the proposed metrics beyond which the ability of a system to cope with a new climatic range is significantly diminished (e.g., Jones, 2004), e.g., the risk of production failures increases.

The metrics are shown below. Examples of the key metrics of climate change policy benefits for the agriculture sector include crop yield and variability, water stress indicators, production and land value, as well as a nutrition index for number of people at risk of hunger.

Proposed set of metrics for impact assessment

	Metric	**Description (Units)**
Biophysical indicators	Crop suitability	Soil and climate factors (no single unit, i.e. different units for different factors)
	Crop yield	Seed Production (Tonne/ha)
	Water stress Index Drought duration Index	Ratio of actual versus potential ET (no units–a ratio) Cumulative water stress over time (no units – a ratio)
Agricultural system characteristics	Land resources	Ratio of used vs. available land (no units – a ratio)
	Regional cereal production	Major cereal crops (Tonne/yr)
	Water resources	Irrigation requirements over availability (no unit – a ratio)
Socio-economic data	Economic value at risk	Net production value; agricultural GDP ($)
	Land value at risk	Land value of areas most affected ($)
	Nutrition index Risk of hunger	Food demand over supply (no units – a ratio) Cumulative number of people whose calorie intake falls below a (FAO-defined) specific value (millions)
Climate policy	Mitigation potential	C-Sequestration committed (Tonne C yr^{-1})

Source: Rosenzweig and Tubiello (2007)

However, this creates a significant problem for CEA, which optimises on a single attribute. It is not possible to compare all of these key indicators, thus either a headline indicator is needed, or some way of drawing in other elements to assess the ranking of options.

In practice, the focus on a specific problem, as in the Mediation case studies (e.g. wine production) might allow a more specific analytical framing to be used, focusing on a key parameter of concern. However, in the context of wider European agriculture, it is clear that the cost-effectiveness framework has significant limitations.

If an economic focus is taken, then it might be possible to use estimates of expected changes in value added from agriculture as a result of climate change, taking account of climatic, allocative and terms of trade effects. The aim of adaptation measures could then be to improve the value added to selected groups of individuals (both producers and consumers).

An evaluation of such measures necessarily requires working through some such models to see who gains and who loses, after account is taken of market linkages. At first this sounds relatively simple, but in practice it would be extremely complicated. This metric uses a high aggregation, when in practice there are a range of scales and aggregation (e.g. adaptation measures at farm level through to national level policy, consideration of local conditions, etc.). At the very least, this would necessitate additional (complementary) analysis. There are also complex issues on socio-economic scenarios as well as climate change to consider. Moreover, many of these measures take the form of providing information and extension services to producers. It can be very difficult to quantify, ex ante, the impacts of these measures on farmer behaviour.

4.4 Water Resources

As with the sectors above, there are many potential impacts on water resources, involving water availability and quality. Moreover, water is a critical core sector and climate change will affect the whole water cycle and water ecosystems, in turn the function and operation of existing water infrastructure (including hydropower, inland navigation, irrigation systems, drinking water supply and waste water treatment) as well as water use in energy supply, agriculture, tourism, industry, etc. There is also a specific geographical focus needed, because the analysis of adaptation measures is likely to take place at the river basin level.

This makes the general application of cost-effectiveness analysis to the water sector extremely difficult, and in practice, there may be a need to consider specific risks and problem types. As an example, it is possible to apply the approach to look at public water supply and the available water availability. Projections are available of future water demand and supply going forward 30 years and against this it is possible to look at the changes from climate change and examine if there is a gap between demand and supply. A cost-effectiveness approach can then be used to rank options (e.g. supply and demand side options) to fill this gap, based on the cost per cubic meter of water delivered.

In other sectors, where there are multiple uses, including ecosystem services, the concept will be more difficult to apply, because of the need to optimise against several criteria. This will be explored as one of the Mediation case studies.

Applications of CEA
This approach has been applied to the water supply system, with an example from the UK in the box below.

This approach does not, however, cover environmental aspects or water quality impacts. Measures to address water quality can possibly be addressed in terms of the costs of meeting given standards for different uses, or acceptable flow levels for rivers. Measures for environment could be based on a similar approach, i.e. based around water quality objectives or environmental objectives, and applying a classic cost-effectiveness approach.

Other examples include the application to the water sector at the developing country level (McKinsey, 2008), which includes that application of the cost curve context to water for India, though this does not include climate change assessment.

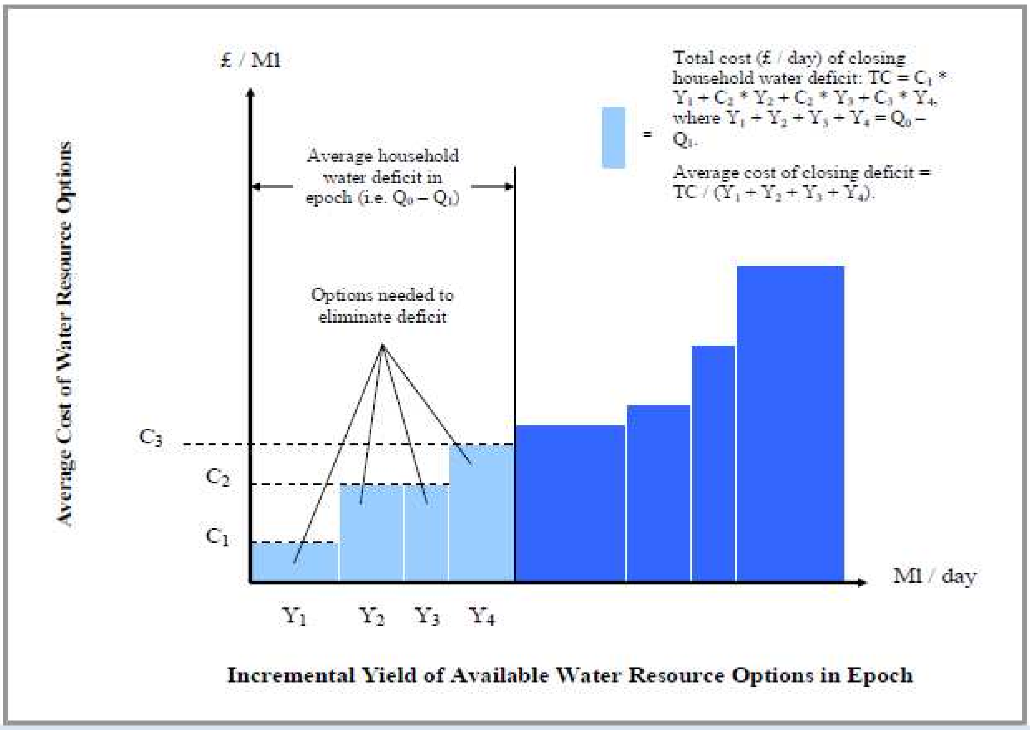
Water Resource Deficits and Cost-Effectiveness of Adaptation

The Defra Cross-regional Research Programme (Project C, Wade et al, 2005) assessed the impact of climate change on the management of water resource zones and existing water infrastructure, including extreme events on water resources, with a focus on two regions (the South-East of England and the South-East of Scotland), both of which are under pressure from climate variability and population growth, and are vulnerable to drought conditions. The study assessed each of the catchments and assessed the 30-year average household water deficit each time period (2011-2040, 2041-2070 and 2071-2100) for each of the four UKCIP climate-socioeconomic scenarios.

Table 1: Estimated Household Water Deficit for SE England Case Study

		Population	Households	Household Demand	Total Demand	Total Demand Plus Headroom	Total Supply	Total Deficit	Total Household Deficit	Total Household Deficit
		(number)	(number)	(Ml / day)	(Ml / day)	(Ml / day)	(Ml / day)	(Ml / day)	(Ml / day)	(m3 / HH / yr)
GSLE	2006	770,830	350,377	124.1	269.8	277.9	273.2	4.7	2.2	2.3
	2020s	889,576	404,353	134.6	292.6	301.9	286.8	15.1	7.0	6.3
	2050s	1,075,308	488,776	141.3	307.1	316.3	294.4	22.0	10.1	7.5
	2080s	1,257,995	571,816	157.7	342.7	353.0	297.4	55.6	25.6	16.3
GSHE	2006	770,830	350,377	124.1	269.8	277.9	273.2	4.7	2.2	2.3
	2020s	889,576	404,353	136.1	295.9	305.4	291.8	13.6	6.3	5.7
	2050s	1,075,308	488,776	146.3	318.0	327.6	297.4	30.2	13.9	10.4
	2080s	1,257,995	571,816	168.6	366.5	377.5	297.4	80.2	36.9	23.5
WMLE	2006	770,830	385,415	124.1	269.8	277.9	273.2	4.7	2.2	2.1
	2020s	913,326	456,663	140.7	306.0	316.2	285.9	30.3	13.9	11.1
	2050s	1,155,690	577,845	171.7	373.3	384.5	293.5	91.0	41.9	26.4
	2080s	1,411,451	705,726	212.0	460.9	474.7	296.5	178.2	82.0	42.4
WMHE	2006	770,830	385,415	124.1	269.8	277.9	273.2	4.7	2.2	2.1
	2020s	913,326	456,663	141.6	307.9	317.1	270.7	46.4	21.4	17.1
	2050s	1,155,690	577,845	174.5	379.3	390.7	265.1	125.7	57.8	36.5
	2080s	1,411,451	705,726	219.7	477.7	492.0	265.1	227.0	104.4	54.0

The cross regional research study (E) (Boyd et al (2006), in Metroeconomica et al. (2006) expanded the analysis and investigated the cost of addressing the water deficit, using information from Wade et al on the range of options for managing public water supply (including options that reduce demand and options that increase supplies), and by constructing indicative cost-yield curves (cost-effectiveness curves), to estimate how to eliminate the household water deficit at minimum cost.



Source: Boyd et al (2006)

4.5 Built Environment and Infrastructure

The issue of floods was discussed earlier. The risks to the built environment and wider infrastructure include a very large number of potential risks, which makes the analysis of cost-effectiveness difficult; it really requires an analysis for the specific risk and type of infrastructure. In reality, this is really a cross-cutting, cross-sectoral theme.

For some infrastructure, e.g. transport infrastructure, there are existing design standards and acceptable levels of risks, and these can form objectives for cost-effectiveness analysis of adaptation, i.e. in relation to maintaining current levels of risk protection.

For the built environment, there are some threshold levels in many Member States, e.g. occupational standards for maximum temperature in buildings, which provides an objective in terms of the costs of reducing the risk of overheating. It might also be possible to provide an analysis of the cost per unit of cooling delivered in a standard MACC analysis.

4.6 Biodiversity and Ecosystem Services

The costs of adaptation for measures for ecosystems and ecosystem services are not well characterised in the literature, and information on adaptation costs and benefits is not focused on biodiversity or ecosystems (Parry et al., 2007).

There is some work in Europe on the effects of climate change on climate space (envelopes) and ecosystems, as well as ecosystem targets.

However, there is a well-established practice of cost-effectiveness analysis in the air pollution field, in relation to critical loads and levels. Similar approaches might be possible for adaptation, in relation to critical thresholds as objectives, i.e. target levels that should ensure sustainability of the relevant ecosystems. The impacts of different adaptation actions in reducing these exceedences can then be estimated and the least cost set of actions then form the required response.

One possible area where such target based approaches could be adopted is with respect to existing conventions and protected sites (e.g. Special Areas of Conservation under the EC Habitats Directive, Natura 2000, etc.). However, even this approach is challenging, notably because it requires agreement (and underlying scientific analysis) of the safe protection levels for ecosystems and species.

There might be a similar approach possible in terms of preserving ecosystem services, which might allow some application of cost-effectiveness analysis, at least for those services which are more amenable to quantification.

4.7 Business, Industry and Services

The very wide range of impacts – and the very large and broad nature of the business and industry sector which makes it difficult to recommend general metrics for cost-effectiveness analysis. There is some potential from considering net value added to the sector or sectors concerned, relative to the situation with no adaptation, i.e. to compare to the costs as for project and policy assessments. There might also be some potential to look at acceptable risk levels for infrastructure or acceptable risks for service supply.

4.8 Summary of Metrics

The discussion above is summarised in the Table below.

Examples of possible metrics / objectives for adaptation cost effectiveness analysis

Sector	Possible Metric	Issues
Health	Cost per DALY, cost per fatality or cost per life year saved (all impact metrics). Some health thresholds exist (maximum occupational temperatures, comfort levels)	Different cost per life year used across Europe. Not capture occupational health. Consistency issues with other sectors where health a part of wider risks (e.g. floods, transport)
Sea level rise	Cost per reduction in land area at risk or number of people at risk (exposure metric) or expected annual damages (economic metric) Cost per ha. For the measure relative to value of land protected per ha (impact metric). Pre-defined acceptable risks of flooding as objective / threshold level for adaptation	Land area and ha only covers small sub-set of SLR impacts. Issue of non-market values, loss of biodiversity and ecosystem services. Very different levels of acceptable risk and protection across Member States
Floods	As above.	As above.
Agriculture	Impact based metrics include cost per unit of crop yield, reduction in water stress, production or land value. Possible headline indicator is cost per change in value added as a result of adaptation measures.	Issue of capturing wider environmental and multi-functionality of agriculture Highly aggregated and only one element of potential impacts.
Water resources	Impact metrics for water availability (household) and cost per M^3 of water provided. Possible thresholds in terms of environmental quality (Directives) or acceptable flows. Possible thresholds for risk of supply disruption.	Issues with wider attributes of water including quality (environmental). Issue were multi-functionality and multiple users and sectors (agriculture, industry, etc.)
Ecosystems and Biodiversity	Critical targets (sustainable levels) and standards (overall objective). Possible cost per unit of ecosystem services.	Issue if standards are available (and complex and contentious to set).
Business & industry	Possible headline indicator is cost per change in value added as a result of adaptation measures. Could also include acceptable risk levels for infrastructure or service supply.	Broad nature of sector and potential risk.
Cross-cutting/cross-sectoral theme		
Extreme Events (including infrastructure)	Possible metric in terms of cost per level of risk reduction, or pre-defined acceptable levels of risks as objective	Very different levels of acceptable risk and protection across Member States Variability in risk acceptability across different extremes, and for different infrastructure.

Note that other possible sectors should be added to this list, including forestry, energy, transport, tourism and marine.

This demonstrates that the application of CEA will be easier for some sectors than others. It is also worth highlighting that in terms of sector objectives, there will be differences on a Member State basis (e.g. in relation to existing objectives) and thus some care will be needed in the case studies.

It is also highlighted that in many cases, the relevant metric will change with the study objectives, the aggregation level (e.g. national vs. local) or the time-scale of the problem (short-term versus long-term).

5. Discussion of Cost-Effectiveness for the Mediation Case Studies

The previous chapter highlights some of the issues in applying cost-effectiveness analysis to adaptation. Going forward, two issues are relevant for Mediation.

- How to apply the lessons above to the Mediation case studies.
- How to translate these lessons, and the information from the case studies, into the common platform.

The early focus in Mediation will be on the practical application of cost-effectiveness to a number of the case studies, which in turn will help the information provision and provide examples for the common platform.

The potential for cost-effectiveness is considered for the full list of potential case studies below. This shows that for most case studies, application should be possible.

Potential for Cost-Effectiveness in the Mediation Case Studies

Focal region	code	Location	Main theme	Cost-effectiveness potential
Northern Europe	NE1	Norway/Sweden /Finland	Health/elderly - Vulnerability mapping	Use of CEA based on cost per death or illness (or DALY) avoided.
	NE2	Finland	Landuse/biodiversity	Potential use of CEA for biodiversity protection, if ecosystem sustainability limits exist, though analysis of effectiveness may be challenging.
Western Europe	WE1	Rhine basin	River discharge	Possible use of CEA in terms of acceptable (tolerable) levels of flood risk, but possible issues with cross-sectoral issues
	WE2	Netherlands	Salt water intrusion	Possible use of CEA for protection or acceptable level of risk of intrusion.
	WE3	Rhine Germany	Forest in flood plains	Possible use of CEA in terms of acceptable (tolerable) levels of flood risk, or consideration of cost per unit of improved forest production, Issue of wider forest services could be captured by ecosystem thresholds.
Central/ Eastern Europe	CE1	Albania	Water scarcity/ agriculture/hydropower	For water scarcity could use CEA on acceptable risk levels of drought or costs of supply (M^3 delivered). Alternative would be to consider agriculture in terms of yield improvement or value added. For hydropower could be based on levels of supply disruption or minimum annual generation.
	CE2	Serbia	Water scarcity and quality/agriculture	For water scarcity could use CEA on acceptable risk levels of drought or costs of supply (M^3 delivered). Alternative would be to consider agriculture in terms of yield improvement or value added.

	CE3	*Poland/ Wroclaw*	*Urban problems*	More information needed.
	CE4	*Poland*	*Flood safety*	Use of CEA in terms of acceptable (tolerable) levels of risk, o
Southern Europe	SE1	Tuscany	Agriculture and landscape	Possible use of CEA in terms of yield improvement or value added. Landscape more challenging
	SE2	Tuscany	Heat and tourism	For health, use of CEA based on cost per death or illness (or DALY) avoided. For tourism more uncertain.
	SE3	Guadiana	Droughts/agriculture	For water scarcity could use CEA on acceptable risk levels of drought or costs of supply (M^3 delivered). Alternative would be to consider agriculture in terms of yield improvement or value added. Issues of capturing multiple sectors and also ecosystem aspects (multiple attributes and sectors)
	SE4	Guadalqivir	Droughts/agriculture	
EU-wide	EU1	EU-wide	Agricultural yields	Possible use of CEA in terms of yield improvement or value added
	EU2	*EU-wide*	*Floods*	Use of CEA in terms of acceptable (tolerable) levels of flood risk
	EU3	*EU-wide*	*Forest fires*	Possible use of CEA in terms of levels of acceptable fire risk.

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